I28.155:
36-80
Geol Survey

PB80-158983

A STUDY OF ROOF FALLS IN UNDERGROUND MINES ON THE POCAHONTAS NUMBER 3 SEAM, SOUTHERN WEST VIRGINIA AND SOUTHWESTERN VIRGINIA

University of South Carolina
Columbia, South Carolina

Prepared for
Bureau of Mines
Washington, D. C.

September 1978

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
NTIS

UNIVERSITY OF
ILLINOIS LIBRARY
URBANA-CHAMPAIGN
OAK STREET
LIBRARY FACILITY

BuMines OFR 36-80

PB80-154982

A STUDY OF

ROOF FALLS IN UNDERGROUND MINES ON THE POCAHONTAS #3 SEAM

SOUTHERN WEST VIRGINIA AND SOUTHWESTERN VIRGINIA

PREPARED FOR
U.S. BUREAU OF MINES
CONTRACT H0230028

CAROLINA COAL GROUP

BY

JOHN C. FERM
GLORIA C. CUMMINS
LINDA L. McKENNA
ROBERT A. MELTON
DAVID MATHEW
CHARLES MUIR
GERALD E. NORRIS

DEPARTMENT OF GEOLOGY
UNIVERSITY OF SOUTH CAROLINA
COLUMBIA, SOUTH CAROLINA

Bureau of Mines Open File Report 36-80

September 1978

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

NOTICE

THIS DOCUMENT HAS BEEN REPRODUCED FROM THE BEST COPY FURNISHED US BY THE SPONSORING AGENCY. ALTHOUGH IT IS RECOGNIZED THAT CERTAIN PORTIONS ARE ILLEGIBLE, IT IS BEING RELEASED IN THE INTEREST OF MAKING AVAILABLE AS MUCE INFORMATION AS POSSIBLE.

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. BuMines OFR 36-80	2.	3. Recipient's Accession No. PB80-158983
4. Title and Subtitle: A Study of Roof Falls in Underground Mines on the Pocahontas #3 Seam, Southern West Virginia and Southwestern Virginia			5. Report Date: September 1978 6.
7. Author(s): John C. Ferm, Robert A. Melton, Glorida D. Cummins, David Mathew, Linda McKenna, Charles Muir, and Gerald E. Norris			8. Performing Organization Rept. No.
9. Performing Organization Name and Address: Department of Geology, University of South Carolina, Columbia, SC 29208			10. Project/Task/Work Unit No. 11. Contract(C) or Grant(G) No. (C) H0230028 (G)
12. Sponsoring Organization Name and Address: Office of the Director--Minerals Health and Safety Technology, Bureau of Mines, U.S. Department of the Interior, Washington, DC 20241			13. Type of Report & Period Covered: Contract research, June 1973-March 1978 14.

15. Supplementary Notes: Supplements BuMines OFR 1(1)-77 (PB 262 368/AS); BuMines OFR 1(2)-77 (PB 263 369/AS). Approved by the Director, Bureau of Mines, for placement on open file, March 19, 1980.

16. Abstract (Limit: 200 words)

This report summarizes the results of an investigation of geologic factors that contribute to roof quality in underground mines in the Pocahontas No. 3 coalbed in southern West Virginia and southwestern Virginia. The investigation consisted of three phases. The first was selecting for detailed study five mines that represented the range of roof conditions, mining practices, and geologic phenomena. This was accomplished by a statistical analysis of questionnaire data from 35 mines. The second consisted of detailed mapping in a "good" and a "bad" top area in each of the mines and resulted in a qualitative assessment of geologic factors contributing to roof falls. In the third phase, five mines were selected in which most nongeologic factors believed to contribute to roof falls were relatively constant but displayed a wide variety of geologic characteristics. Data from these mines were analyzed to test the qualitative assessments from phase II. The primary results of this investigation is that slickensides arising from different geologic causes are the major geologic features leading to roof falls. These slickensides are found in ancient slump deposits, fire clays and sandy fire clays, and channel contacts. Falls also occur where thick sandstone bodies directly overlying the coal contain abundant shale or ironstone pebbles and coaly strips. The best top material is a sequence that consists of shale grading upward to sandy shale and sandstone within 30 ft of the top of the coal. Thick sandstone units without pebbles also provide good top material.

17. Document Analysis a. Descriptors

Coal mining
Pocahontas No. 3 Geology
Coal mines
Coal mine roof investigations

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group 08I

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Unlimited release by NTIS.	20. Security Class (This Page)	22. Price

Dambrogio 2/3/81 $3.00

Digitized by the Internet Archive
in 2023 with funding from
University of Illinois Urbana-Champaign Alternates

https://archive.org/details/studyofrooffalls00unse

DISCLAIMER NOTICE

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies or recommendations of the Interior Department's Bureau of Mines or of the U.S. Government.

FORWARD

This report was prepared by the University of South Carolina, Geology Department, Columbia, South Carolina, under USBM Contract Number H0230028. The contract was initiated under the Coal Mine Health and Safety Program. It was administered under the technical direction of PRC with Mr. N. Moebs acting as the Technical Project Officer. Mr. D. Askin was the contract administrator for the Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period June, 1973 to March, 1978. This report was submitted by the authors in September, 1978.

TABLE OF CONTENTS

PAGE

1.0 Summary of Phase I and II - Selection of five underground mines and their detailed description 1

1.1 Introduction 2

1.2 Selection of mines for detailed study - Phase I 5

1.2.2 Procedures for Phase I 5

1.2.3 Analysis of Phase I data 5

1.2.3.1 Discriminant function analysis 6

1.2.3.2 Q-Mode factor analysis. 6

1.2.4 Selection of mines for detailed study 10

1.2.4.1 Selection based on statistical analysis . . . 10

1.2.4.2 Other considerations in selection 10

1.2.4.2.1 Underground accessibility 10

1.2.4.2.2 Availability of strip mine exposures 11

1.2.4.2.3 Availability of core hole data . . 11

1.2.4.2.4 Geographic or geologic aspects . . 11

1.3 Detailed study of five selected mines - Phase II 12

1.3.1 Objectives of Phase II 12

1.3.2 Procedures for Phase II 12

1.3.3 Description of mines 13

1.3.3.1 Description of Virginia Pocahontas #3 mine . 13

1.3.3.2 Description of Shannon Branch mine 13

1.3.3.3 Description of Bishop mine 19

1.3.3.4 Description of Keystone II mine 19

1.3.3.5 Description of Macalpin - East Gulf mine . . 24

PAGE

1.3.4 Summary of Phase II results 29

1.3.4.1 Effect of rock types 29

1.3.4.2 Effect of rock sequence 31

1.3.4.3 Effect of channel scouring 31

1.3.4.4 Effect of slickensides 32

2.0 Phase III - Association of geological factors and roof quality in five underground mines in Buchanan County Virginia 33

2.1 Introduction 34

2.2 Site selection 34

2.3 The measurement program 35

2.3.1 Procedures 35

2.3.2 Results of the measurement program 38

2.3.2.1 Roof rock classification and maps showing distribution of rock types 38

2.3.2.2 Roof quality classification and maps showing distribution of roof quality 40

2.4 The analysis program 40

2.4.1 Procedures 52

2.4.2 Results of the analysis program 53

2.4.2.1 Association of rock type and roof quality . . 53

2.4.2.2 Analysis of entry length of good and bad top relative to rock type 70

2.4.3 Summary of results of analyses 74

3.0 Summary of results from Phase II and III 76

4.0 A summary for operating personnel 80

LIST OF FIGURES

PHASE I & II PAGE

Figure 1 Aerial distribution of Pocahontas #3 coal bed in southern West Virginia and location of mines in this report. 3

Figure 2 Roof rock map of Virginia Pocahontas #3 Mine, Island Creek Coal Company. 14

Figure 3 Cross section along line A-A'. 15

Figure 4 Roof rock map of Shannon Branch Mine, Allied Chemical Company. 16

Figure 5 Cross section along line B-B'. 17

Figure 6 Roof rock map of Bishop Mine, Consolidation Coal Company. 20

Figure 7 Cross section along line C-C'. 21

Figure 8 Roof rock map of Keystone II, Eastern Associated Coal Company. 23

Figure 9 Cross section along line D-D'. 25

Figure 10 Roof rock map of Macalpin, East-Gulf Mine, Westmoreland Coal Company 27

PHASE III

Figure 11 Location map for Island Creek Coal Company Mines, Virginia Pocahontas Division. 36

Figure 12 Rock types in the Beatrice Mine. 41

Figure 13 Roof quality in the Beatrice Mine. 42

Figure 14 Rock types in the Virginia Pocahontas #1 Mine. 43

Figure 15 Roof quality in the Virginia Pocahontas #1 Mine. 44

Figure 16 Rock types in the Virginia Pocahontas #2 Mine. 45

Figure 17 Roof quality in the Virginia Pocahontas #2 Mine. 46

Figure 18 Rock types in the Virginia Pocahontas #3 Mine. 47

PAGE

Figure 19 Roof quality in the Virginia Pocahontas #3 Mine. . . . 48

Figure 20 Rock types in the Virginia Pocahontas #4 Mine. 49

Figure 21 Roof quality in the Virginia Pocahontas #4 Mine. . . . 50

Figure 22 A model of lateral relationships of the rock types and sequences in the Virginia Pocahontas Division, Island Creek Coal Company. 51

LIST OF TABLES

		PAGE
Table 1	Results of discriminant analysis according to mine	7
Table 2	Grouping of the mines based on Q-mode factor analysis. . . .	9
Table 3	Overall chi square results of rock type and roof quality comparisons for Beatrice Mine.	54
Table 4	Orthogonal comparisons of thick sandstone, low splay and high splay vs. thick shale and roof quality for Beatrice Mine.	54
Table 5	Orthogonal comparisons of thick sandstone and low splay vs. high splay and roof quality for Beatrice Mine.	55
Table 6	Orthogonal comparisons thick sandstone vs. low splay and roof quality for Beatrice Mine.	55
Table 7	Orthogonal comparisons of good and moderate vs. bad and fallen roof quality and rock types for Beatrice Mine.	56
Table 8	Orthogonal comparisons of good and moderate vs. bad roof quality and rock types for Beatrice Mine.	56
Table 9	Orthogonal Comparisons for good vs. moderate roof quality and rock types for Beatrice Mine.	57
Table 10	Overall chi square results of rock type and roof quality comparisons for Virginia Pocahontas #1 Mine.	59
Table 11	Orthogonal comparisons of thick sandstone and low splay vs. thick shale and roof quality for Virginia Pocahontas #1 Mine.	59
Table 12	Orthogonal comparisons of thick sandstone vs. low splay and roof quality for Virginia Pocahontas #1 Mine.	60
Table 13	Orthogonal comparisons of good and moderate vs. bad and fallen roof quality and rock type for Virginia Pocahontas #1 Mine.	60
Table 14	Orthogonal comparisons of good and moderate vs. bad roof quality and rock types for Virginia Pocahontas #1 Mine.	61
Table 15	Overall chi square results of rock type and roof quality comparisons Virginia Pocahontas #2 Mine.	62

PAGE

Table 16 Orthogonal comparisons of thick sandstone and low splay vs. thick shale and roof quality for Virginia Pocahontas #2 Mine. 62

Table 17 Orthogonal comparisons of thick sandstone vs. low splay and roof quality for Virginia Pocahontas #2 Mine. 63

Table 18 Orthogonal comparisons of good and moderate vs. bad and fallen roof quality and rock type for Virginia Pocahontas #2 Mine. 63

Table 19 Orthogonal comparison of good and moderate vs. bad roof quality and rock type for Virginia Pocahontas #2 Mine. 64

Table 20 Overall chi square results of rock type and roof quality comparison for Virginia Pocahontas #3 Mine. 66

Table 21 Orthogonal comparison of thick sandstone and orthoquartzite sandstone vs. thick shale and roof quality for Virginia Pocahontas #3 Mine. 66

Table 22 Orthogonal comparisons of thick sandstone vs. orthoquartzite sandstone and roof quality for Virginia Pocahontas #3 Mine. 67

Table 23 Orthogonal comparisons of good and moderate vs. bad and fallen roof quality and rock type for Virginia Pocahontas #3 Mine. 67

Table 24 Orthogonal comparisons of good and moderate vs. bad roof quality and rock type for Virginia Pocahontas #3 Mine. 68

Table 25 Overall chi square results of rock type and roof quality comparisons for Virginia Pocahontas #4 Mine. 69

Table 26 Orthogonal comparisons of good and moderate vs. bad and fallen roof quality and rock type for Virginia Pocahontas #4 mine. 69

Table 27 Overall chi square results of rock type and roof quality comparisons across all mines in the Virginia Pocahontas Division. 71

PAGE

Table 28 Means for linear entry distances of good-moderate and bad-fallen top composed of thick sandstone, low and high splay deposits, orthoquartzite sandstone and thick shale. 72

Table 29 Analysis of variance of rock types in linear distance of entry with good or moderate top. 73

Table 30 Analysis of variance of rock types in linear distance of entry with bad or fallen top. 73

LIST OF PLATES

PHASE I & II

Plate I A. Roof fall in bad top area, Shannon Branch Mine. 18

B. Close up of slickensided shale in bad top area, Shannon Branch Mine. 18

Plate II A. Roof in good top area, Bishop Mine. 22

B. Roof fall in bad top area, Bishop Mine. 22

Plate III A. Roof and drill site of good top area, Keystone II. 26

B. Roof fall in bad top area, Keystone II. 26

Plate IV. A. Roof of good top area, East Gulf Mine. 28

B. Roof fall in bad top area, Macalpin Mine. 28

1.0 SUMMARY OF PHASE I AND II - SELECTION OF FIVE UNDERGROUND MINES AND THEIR DETAILED DESCRIPTION

//

1.1 INTRODUCTION

Roof fall accidents account for approximately one-half of the fatalities in bituminous coal mining. Although many factors are known to contribute to roof falls, the role of geologic factors is least understood. One of the primary reasons is the lack of precise data dealing with rock properties that can be related to roof fall areas. Suggestions have been made that "want" areas, channel sandstones, and similar features related to depositional environments of coal beds and associated rocks may contribute to weakening of roof and thus produce a roof fall hazard, but precise data are needed to establish this point. Should such relationships be strong and firmly established then the major problem is one of stating the probability of roof fall in advance of mining (ie. isolating areas of bad top). Prediction solutions should consider local geologic phenomena and mining practices and arise from comparing areas where geologic and mining characteristics are known to contribute to roof fall hazards to areas where only core hole exploration data is available.

The research presented in this report consists of an investigation of the Pocahontas #3 coal seam in Wyoming and McDowell Counties, West Virginia and adjoining Buchanan County, Virginia describing geologic features in underground coal mines with the view of establishing relationships between geologic attributes in underground coal mines and the occurrence of roof falls.

The Pocahontas #3 seam was chosen to study for several reasons. From a geologic point of view this seam is the most widespread in southern West Virginia and southwestern Virginia (Fig. 1) and hence there are virtually no problems with correlation. The thickness of the seam is uniformly 3 to 6 feet thick over most of the area but in some areas it increases to 15 feet. North and northwest of the area shown in figure 1 the seam thins rapidly and in the south and southwest it is in fault contact with older rocks.

Because of its uniformity and quality, the Pocahontas #3 has been extensively cored and mined over the past century and much information about it is available. In addition, there is much current mining activity on this seam. Six major companies have one or more mines in the seam and at least eight small ones also mine it. Almost all mining is by underground methods with continuous miners being the most prevelant, although there are operating long-walls.

Finally, past experience in the area has indicated that roof quality varies considerably. Operating personnel report falls associated with riders, kettlebottoms, horsebacks, and sandstone channels. Some of these are reported to be minor problems but others are said to be so severe that mining efforts have been abandoned.

Basic data for this study was obtained from existing core hole logs, in-mine cores of roof material, stratascope examination of internal characteristics of roof material, mine maps, interviews with mining engineers, on-site underground inspection, mapping of mining conditions, and mapping and measurement of geologic features in known areas of good and bad roof.

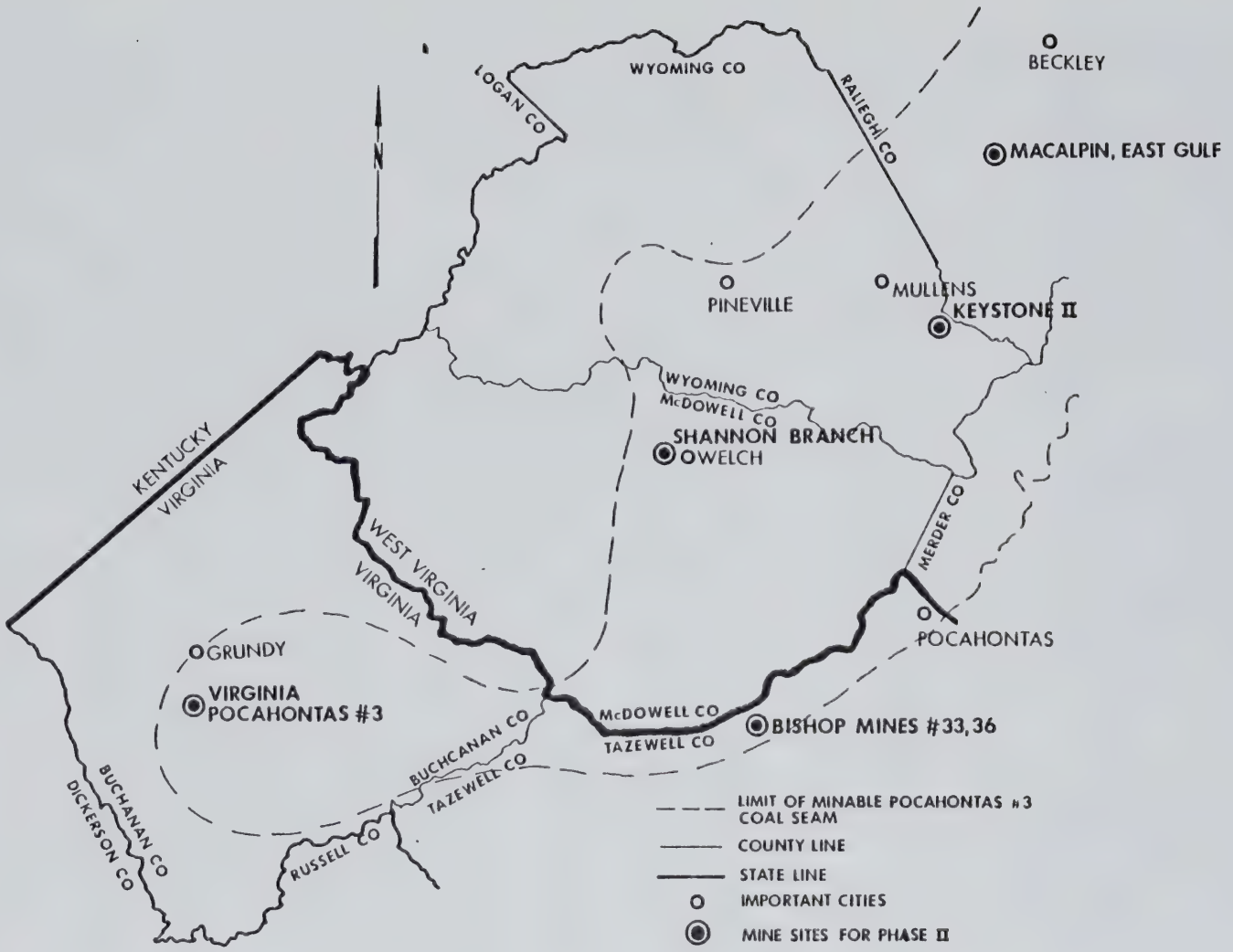


FIGURE 1 AERIAL DISTRIBUTION OF POCAHONTAS #3 COAL BED IN SOUTHERN WEST VIRGINIA & VIRGINIA AND LOCATION OF MINES IN THIS REPORT

Because little basic data is available concerning the precise interrelationship of roof falls to geological characteristics, one of the primary efforts of this study was centered upon the collection and cataloguing of information which can comprise a base for isolating causal elements in the roof fall problem.

The study was divided into two parts: Phase I and Phase II. Detailed results of these studies are given in Ferm and Melton (1975) and summarized in the first part of this report. The objective of Phase I was to select for detailed study five mines in the Pocahontas #3 coal seam which represent the spectrum of variation in roof quality, geologic phenomena, and mining conditions. Phase II consisted of a detailed underground mapping and measurement program in selected fall and adjoining non-fall areas in each of the five mines selected during Phase I.

1.2 SELECTION OF MINES FOR DETAILED STUDY - PHASE I

1.2.1 OBJECTIVES OF PHASE I

The purpose of the first phase of this study was the assessment of variation of roof rock, geologic phenomena, and mining conditions of the Pocahontas #3 coal seam throughout its area of distribution and to select five mines for intensive studies which would document geological factors in the roof rock which could be related to falls.

In order to do this quickly and effectively, a questionnaire was prepared with the help of engineers in the area, Bureau of Mines officials, and engineering consulting firms. The purpose of the questionnaire was to quickly supply the range of variation of mining conditions, roof conditions, and geologic phenomena found in the Pocahontas #3 coal seam throughout the area in which it is mined.

This information was evaluated statistically. On the basis of this evaluation as well as practical considerations, five mines were selected that represented the greatest geological and mining variation found in the Pocahontas #3 coal seam.

1.2.2 PROCEDURES FOR PHASE I

The initial step of Phase I was visiting regional offices of companies mining the Pocahontas #3 seam in order to explain the objectives of the study and to arrange interviews with mine superintendents, mine foremen and/or safety men who would be most familiar with roof quality in Pocahontas #3 mines.

Mine maps were obtained from appropriate engineering offices and taken to the interview for the purpose of locating fall and non-fall areas and other geologic or unusual phenomena.

Persons administering the questionnaire briefly explained the objectives of the program to the respondent, presenting background information and setting the stage for the questionnaire. The respondent was asked to choose a fall area, the worst top in the mine, and non-fall area, the best top in the mine, with which he was familiar and to locate these areas on mine maps and label them fall and non-fall. Forty-eight questionnaires were completed in this fashion.

Data from the questionnaires was transferred to computer data sheets from which the data was key-punched and verified. Each questionnaire was divided into parts; fall and non-fall, and referenced according to question number, mine name and fall and/or non-fall area. Hence for each of forty-eight questionnaires, two cases were generated from each questionnaire (fall or non-fall) for a total of ninety-six cases. These cases were then treated in statistical tests either as pairs, separately, fall groups, non-fall groups or combinations thereof.

1.2.3 ANALYSIS OF PHASE I DATA

Data obtained from the questionnaire were analyzed to determine: (1) the general spectrum of variation in geological and mining

attributes of the Pocahontas #3 coal bed, (2) the degree to which the variation in attributes was associated with certain mines, and (3) the degree to which attributes were associated with fall and non-fall areas. The specific form of analysis consisted of discriminant analysis and Q-mode factor analysis. These results were combined with practical considerations leading to a final selection of mines for detailed study.

1.2.3.1 DISCRIMINANT FUNCTION ANALYSIS (Barr, Goodnight, 1972)

The main objective for using this analysis was (1) to determine whether items of data found in the questionnaire could discriminate between fall and non-fall areas, and (2) to determine whether the analysis could serve as a basis for classification of the mines.

In essence, the analysis consists of an objective search of weighting factors which, when applied to the questionnaire data will indicate whether the geologic and mining data in the questionnaire served as predictors of fall and non-fall areas. Success or failure of this technique rests on two factors: 1) choice of the proper variables (questions in the questionnaire) and 2) assignment of the proper weighting coefficient to each variable.

The results of this analysis, described in detail in Ferm and Melton (1975) and shown on Table 1, are surprisingly good taking into account the subjective nature of the questionnaire. In 13 of 21 cases (two mines were excluded because of insufficient data) the discriminant function correctly distinguished fall areas from non-fall areas on the basis of the questionnaire. In three mines all non-fall areas were correctly classified but some fall areas were incorrectly predicted to be non-fall areas. In three other mines all fall areas were correctly classified but some non-fall areas were assigned to the roof fall category. In only three mines did the function not perform well. These results suggest that such discriminant analysis might be, with further refinement, a useful tool in itself. In terms of this investigation, the analysis helped in two important ways: 1) it demonstrated that the data in the questionnaire did contain information relevant to the roof fall problem and 2) it aided in selection of mines to study in phase II.

Mines improperly discriminated became strong candidates for further study because at these mines probable causes of roof failure not included in the questionnaire could be isolated. Equally important were mines properly discriminated because causes of roof failure gathered with the questionnaire could be sampled with greater precision in these mines.

1.2.3.2. Q-MODE FACTOR ANALYSIS (Barr, Goodnight, 1972).

The second analysis was the Q-mode factor analysis (SAS, 1972). The purpose of this analysis was to produce clusters of mines that have geological, mining, and roof quality attributes that vary in the same way.

TABLE 1. Results of Discriminant analysis according to mine. Jenkins Jones, Keystone I, Itmann 1 are excluded because of insufficient data.

GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
Fall Disc. Non-Fall Disc.	Fall not Disc. Non-Fall Disc.	Fall Disc. Non-Fall not Disc.	Fall Disc. Non-Fall Disc. Non-Fall not Disc.	Fall Disc. Fall not Disc. Non-Fall Disc.
Macalpin	East Gulf	Shannon Branch	Itmann III	V. P. #1
Keystone II	Keystone IV	Turkey Gap	Maitland	
Keystone V	U.S.S. #14	V. P. #2		
Itman II				
Kepler				
Bishop				
Beech Fork				
Superior				
Slab Fork #10				
U.S.S. #10				
Beatrice				
U.S.S. #9				
V. P. #3				

Steps in the application of Q-mode factor analysis include: 1) selection of variables for analysis, 2) selection of mines for analysis, 3) standardization of scores (after Nunnally, 1967), 4) transposition of the matrix, 5) listing of missing values, 6) specification of five factors, 7) factor analysis, and 8) assignment of mines used in the analysis to one of five groups.

Some of the variables selected for analysis, eg. presence or absence of layering and presence or absence of distorted roof rock, were believed to be of questionable integrity, but because factor analysis is generally regarded as being a robust test, they were included nonetheless. Moreover, because the function of the test was essentially a procedure for grouping mines with similar variation, the risks were probably not great. Data with high skewness were overcome by standardization of scores as described by Nunnally (1967).

The mines selected for analysis were:

Macalpin
East Gulf
Keystone I
Keystone II & III
Keystone IV
Keystone V
Shannon Branch
Turkey Gap
Buckeye
Itmann II
Itmann I
Kepler
U.S.S. #4
Itmann III
Maitland
Tralee
Bishop
Beech Fork
Jenkin Jones
Superior
U.S.S. #10
Beatrice
V.P. #4
V.P. #1
V.P. #2
V.P. #3
Slab Fork #10

Assignment of mines to one of 5 groups was accomplished by assigning each mine a number from 1 to 5 based on the factor that contained the highest factor loading for that mine. For example, if mine "A" has factor loadings .465, .774, .213, .954 and .667 for factors 1 through 5 respectively, it is readily apparent that factor 4 (or .954) (factor loading) would be the most appropriate. The results of this analysis are summarized in Table 2.

Table 2. Grouping of the mines based on Q-mode factor analysis. The mines are grouped according to their high factor loadings and ranked within groups from highest to lowest (top to bottom) factor loading.

GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
Superior	Bishop	U.S.S. #10	Macalpin	Keystone II & III
V. P. #1	Itmann I	Kepler	East Gulf	East Gulf
U.S.S. #14	V. P. #4	V. P. #3		Beech Fork
Maitland	Shannon Branch	Jenkin Jones		Turkey Gap
Maitland	Slab Fork #10	Jenkin Jones		U.S.S. #14
Itmann #2	Keystone IV			
Keystone V	Superior			
Itmann #3	V. P. #2			
V. P. #4	V. P. #2			
Macalpin	Buckeye			
Macalpin				
Keystone II & III				
Beatrice				

1.2.4 SELECTION OF MINES FOR DETAILED STUDY

Selection of mines for detailed study was based on (1) the statistical analysis of questionnaire data which was believed to reflect the spectrum of variation of roof, mining, and geological attributes of the Pocahontas #3 coal bed, (2) considerations of a practical nature, and (3) those geological attributes not reflected in the questionnaire.

1.2.4.1 SELECTION BASED ON STATISTICAL ANALYSIS

The principal basis of selection with regard to the statistical analysis was the results of the factor analysis as it provided a series of classes for all mines with ranking within classes. The discriminant analysis supplied supplementary information.

Results of the factor analysis, shown in Table 2 , indicate mines within each of the five groups arranged in diminishing rank of factor loadings. Thus, on the basis of the factor analysis alone, the mines listed at the top of each group should be the most appropriate for underground sampling.

The results of the discriminant analysis are shown in Table 1. On this table the mines are grouped on the basis of having reported fall or non-fall areas which the analysis discriminated or failed to discriminate. It should be noted that there are five such groupings. In Group 1, which included most mines, the analysis was able to discriminate and non-fall attributes. In Group 2, non-falls were discriminated and falls were not. In the few mines that made up Group 3, falls were discriminated and non-falls were not. Groups 4 and 5, comprising a total of three mines, illustrated a greater variety of results.

With the factor analysis defining the five basic groups, the discriminant analysis results were added by selecting mines that represented both the discriminant groups and the factor groups. Table 1 shows mines representing discriminant groups 1, 2, 3 and 4. Table 2 shows mines in factors 1 through 5 with high factor loadings. Mines representing each group from the discriminant analysis and each factor from the Q-mode analysis were selected as ideal mines for Phase II study. These were: Macalpin, Shannon Branch, Maitland, U.S.S. #10 and East Gulf.

1.2.4.2 OTHER CONSIDERATIONS IN SELECTION

The five mines chosen on the basis of statistical results were also considered from the point of view of the following factors which though important are not readily treated in a quantitative fashion:

1.2.4.2.1 UNDERGROUND ACCESSIBILITY

Many of the mines in the study have been largely retreated with little access to underground areas. Because of this U.S.S. #10 had to be eliminated.

1.2.4.2.2 AVAILABILITY OF STRIP MINE EXPOSURES

One of the important aspects of geological study of roof problems lies in the difficulty in seeing the kind and distribution of rock types slightly above the immediate roof of the mine. Such data can be partially derived from core hole records and in roof coring but information of this type can be obtained more rapidly in strip mine highwalls. Only the Bishop mine had this quality, but some surface exposures do occur near Keystone II. Maitland on the other hand was eliminated because it lacked core hole data and nearby surface exposures.

1.2.4.2.3 AVAILABILITY OF CORE HOLE DATA

As in the case of strip mine data, core holes provide knowledge of rocks lying slightly above the immediate roof and also show, in a preliminary way, the pattern of lithic variation throughout the mine. All mines had a reasonable quantity of such data and none were excluded on this basis.

1.2.4.2.4 GEOGRAPHIC OR GEOLOGIC ASPECTS

Although geographic location within the Pocahontas #3 coal field is not known to be directly related to geologic association with roof quality, it was at least considered and, in conjunction with other factors, did produce adequate geographic spread. In addition, some mines such as those in Buchanan county which are extraordinarily deep and those along the southeastern margin of the field which have experienced a greater degree of tectonic deformation were included. One mine in each of these two settings was chosen, i.e. Bishop and Virginia Pocahontas #3.

Finally, consideration was given to avoiding too many mines from a single company. Whether as a nuisance or a source of benefit, it was thought advisable to distribute efforts in mines to as many companies as possible.

Thus, both on the basis of results of statistical and other considerations, Macalpin-East Gulf, Westmoreland Coal Company; Shannon Branch, Allied Chemical; Virginia Pocahontas #3, Island Creek Coal Company; Keystone II and III, Eastern Associated Coal Company and Bishop, Consolidation Coal Company were selected for detailed study. Their location is indicated on Figure 1.

1.3 DETAILED STUDY OF FIVE SELECTED MINES - PHASE II

1.3.1 OBJECTIVES OF PHASE II

With the selection of five mines that reflect the maximum variation in lithologic characteristics, degree of roof stability and geographic and geologic distribution, the principle objective of the next phase of the study was the detailed examination of geologic and roof characteristics of "good" and "bad" top areas within each of the five mines. This selection of "good" and "bad" top is a very important point. If geologic factors are the same in both "good and "bad" top areas, then geology is essentially not responsible for roof failure. If, on the other hand, kinds of geological features are associated with "good" and "bad" top, then a major predictive criteria for roof conditions is available.

The principal steps in this study were:

1. Selection of good and bad areas within each mine.

2. Within each good and bad top areas to document rock types, rock sequences, aerial distribution of rock type and sequences and other geologic phenomena which may be related to roof stability.

3. Document mining practices in good and bad top areas that may be related to roof instability.

4. Obtain three-inch diameter roof cores for physical testing.

1.3.2 PROCEDURES FOR PHASE II

For each of the five mines selected for detailed study, the first step in the investigation was a detailed interview with relevant personnel of the mine. The objective of the interview was to obtain a detailed mine map on which were indicated mining methods, advance or retreat status of various parts of the mine, areas reputed to have good or bad top, and the nature of roof falls. In addition, any core hole information not obtained at the Phase I interview were collected and arrangements were made for an underground reconnaissance. Following this, each mine was visited underground for reconnaissance purposes, which verified facts obtained during the interview and provided a basis for selection of detailed study sites. Areas for detailed study were then selected in consultation with mine personnel. Important considerations included: 1) clear definition of potential study areas as being samples of best and worst top in the mine, 2) accessibility of selected areas with respect to transport, ventilation, and non-interference with working areas and 3) proximity to water and compressed air for drilling. Detailed studies in these areas included geologic mapping of roof rock and distribution of falls and coring of roof rock. Such detailed mapping required about three weeks for each mine.

1.3.3 DESCRIPTION OF MINES

1.3.3.1 DESCRIPTION OF VIRGINIA POCAHONTAS #3 MINE

Coal height in Virginia Pocahontas #3 is approximately 42 to 50 inches with a few minor splits. The coal has strong closely spaced vertical joints and, as a result, the ribs are generally crushed and broken. The floor of the coal seam has gently rolling topography with a few small east-west trending swags. Shale is the dominant rock type above the coal seam and generally extends 10 to 40 feet above the coal. Overlying the shale is a sandy shale, which is in turn overlain by a flazered sandstone that gently undulates well above the Pocahontas #3 seam (Fig. 2). The flazered sandstone is overlain by a hard massive quartzite which is quite thick and, although not shown on the figures ranges between 50 feet to 150 feet thick in this and surrounding areas.

In the good top area, the sequence of rock is similar to that which is seen throughout the rest of Virginia Pocahontas #3 (Fig. 3). The coal is overlain by 10 to 20 feet of a coarsening upward sequence of shale and coal streaks, sandy shale with a few plant bearing layers, and a flazered sandstone which changes abruptly to clean quartz sandstone.

In the bad top area, the clean quartz sandstone is replaced by a hard brittle orthoquartzite sandstone containing quartz pebbles approximately ½ inch in diameter. When this orthoquartzite scours down to the top of the coal, the roof usually can be held only with great difficulty.

1.3.3.2 DESCRIPTION OF SHANNON BRANCH MINE

The Pocahontas #3 seam in Shannon Branch mine is approximately 48 to 50 inches in height and dips gently toward the northwest. Local swags trending approximately east-west are common. The distribution of the rock types between the Pocahontas #3 and #4 coal seams is shown in Fig. 4. Of the four basic rock bodies above the seam, the most significant is a trough-like body of interbedded sandstone and shale which extends from the western margin east-northeastward to the east central protion of the property. This trough is surrounded by shale (Fig. 5). In the western portion of Shannon Branch, where mining takes place near the contact of the trough and the shales or under the trough, serious difficulty with roof support occurs.

The roof of the bad top area is made up of a number of different rock types and falls have a preferred orientation and association to specific rock types. In the middle of the bad top area the largest falls occur in slickensided shale found adjacent to hard fine to coarse grained sandstone bellies which meander through a large portion of the trough shown in Figure 5 and Plate 1. In the northermost portion of the bad top area, falls occur where a 2 to 4 foot layer of slickensided shale overlying the coal is unevenly overlain by a hard medium-grained sandstone conglomerate. In some places, masses of sandstone conglomerate scour

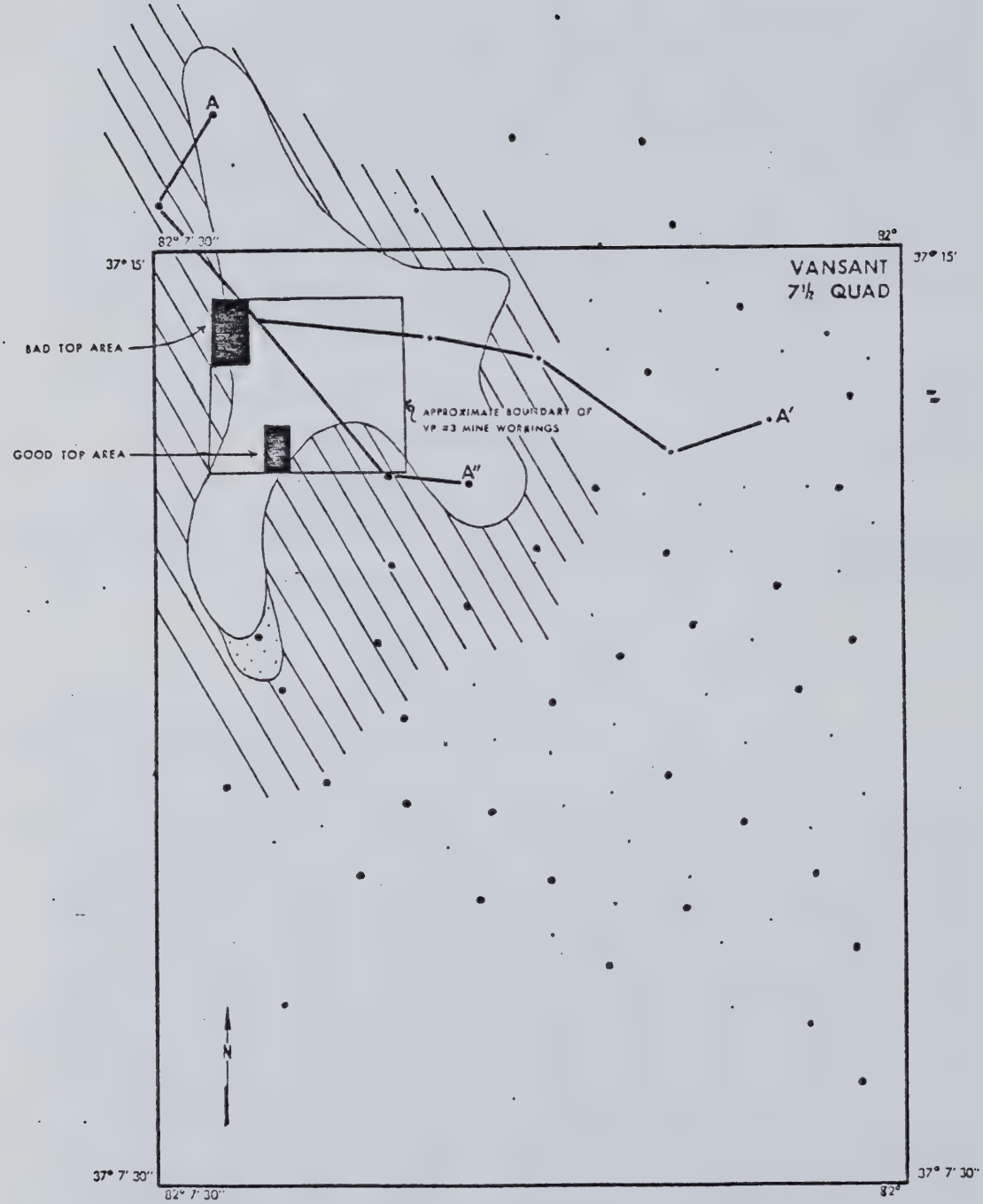


FIGURE 2 ROOF ROCK MAP OF VIRGINIA POCAHONTAS #3 MINE
ISLAND CREEK COAL COMPANY (SEE FIG 1 FOR LOCATION)

24

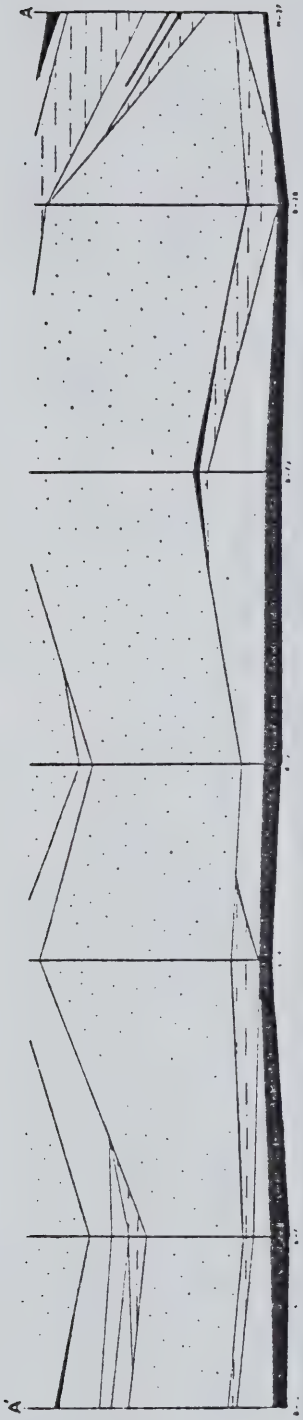


FIG. 3 CROSS SECTION ALONG LINE A-A' (FOR LOCATION SEE FIG. 2)

SANDSTONE
SHALE
SANDY SHALE
COAL

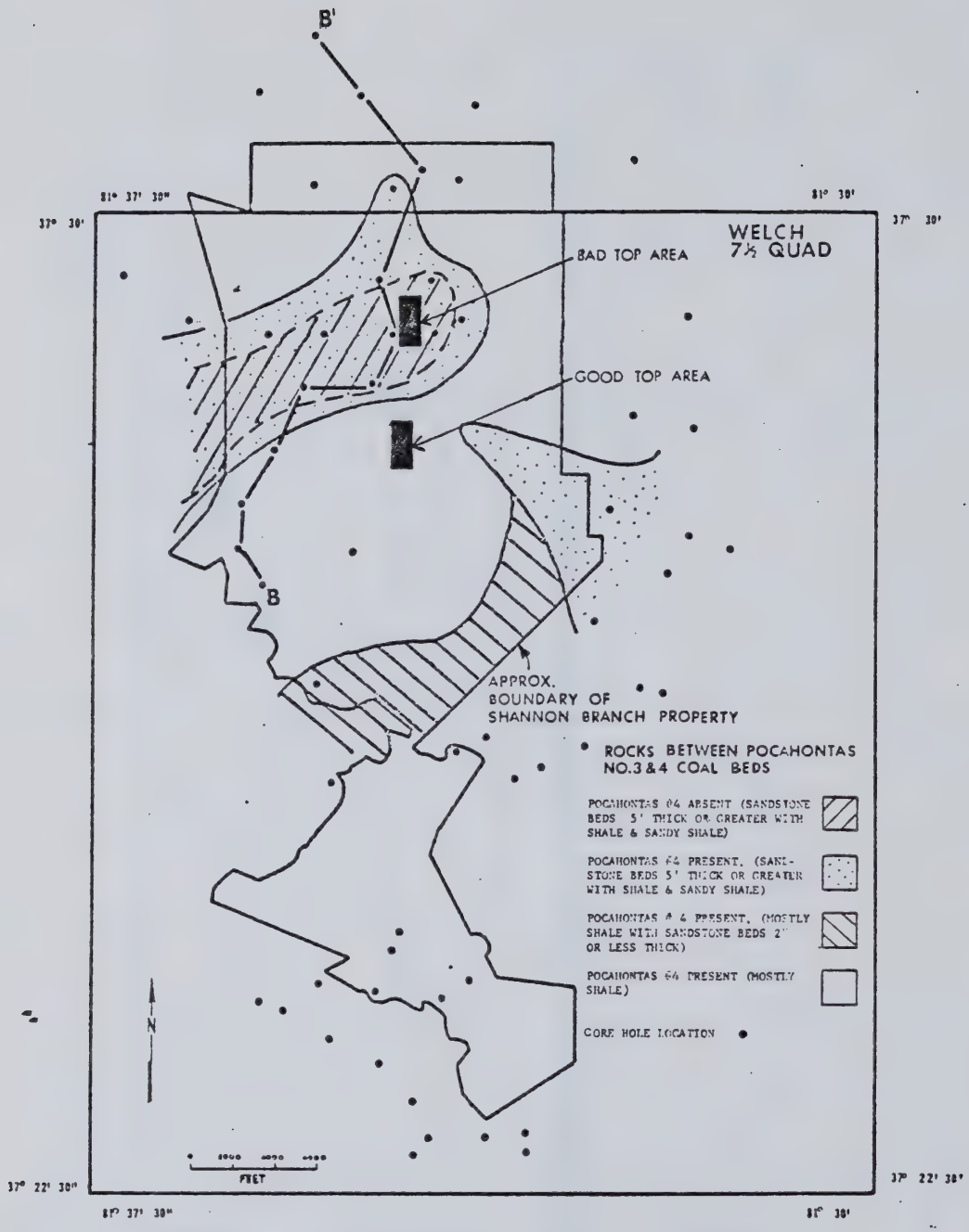


FIGURE 4 ROOF ROCK MAP OF SHANNON BRANCH MINE ALLIED CHEMICAL CO.
(SEE FIG 1 FOR LOCATION)

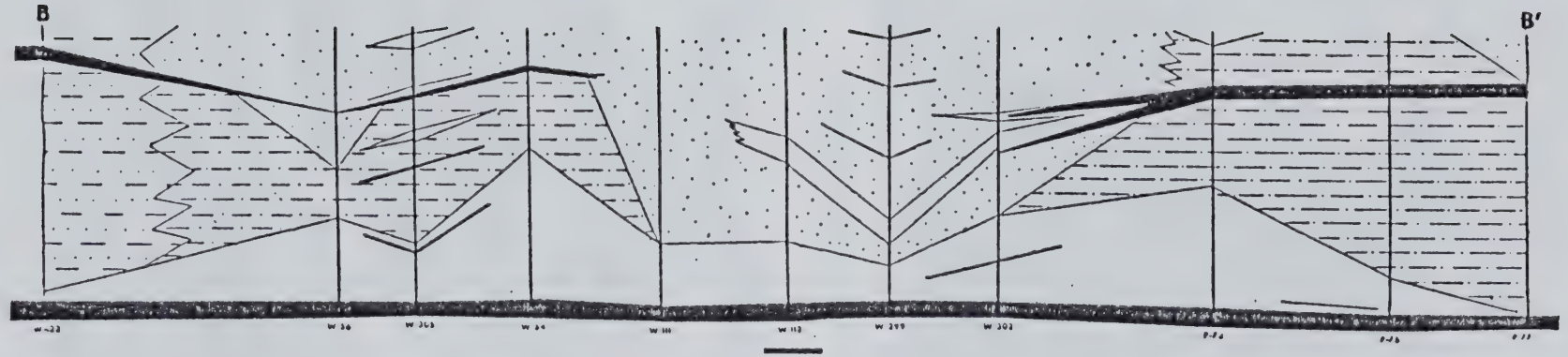


FIG. 5 CROSS SECTION ALONG LINE B-B' (FOR LOCATION SEE FIG. 4)

SANDSTONE

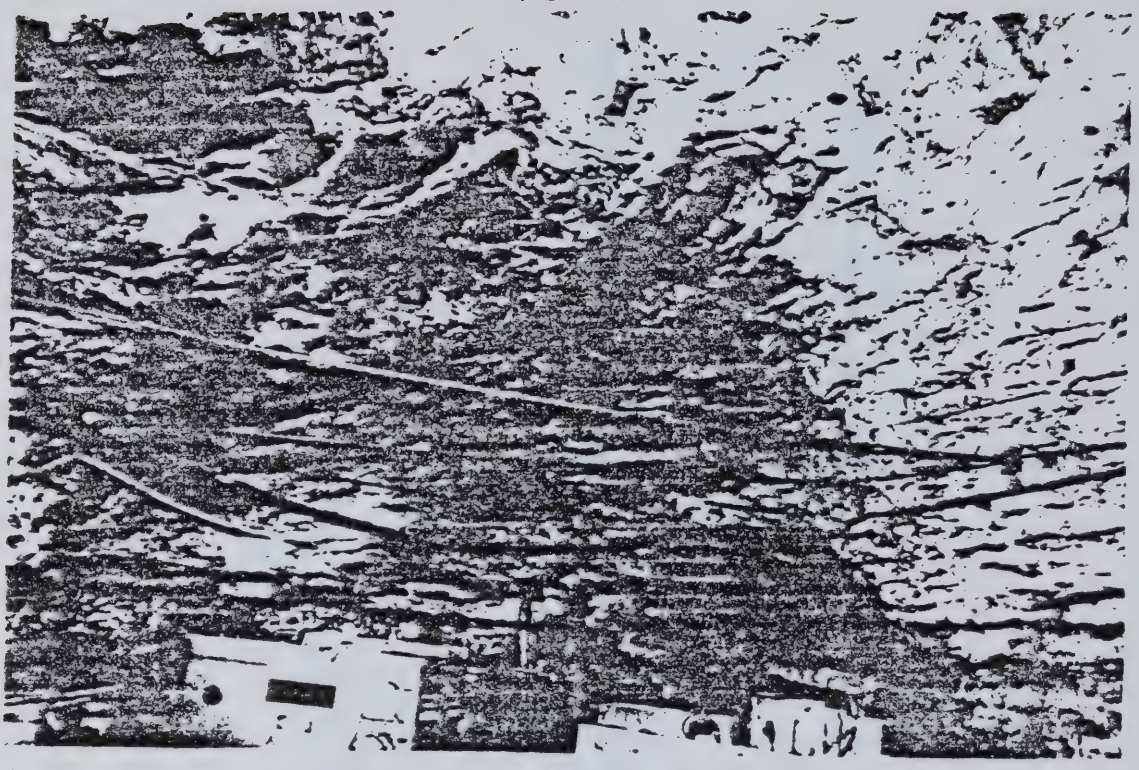
SHALE

SANDSTONE & SHALE INTERBEDDED

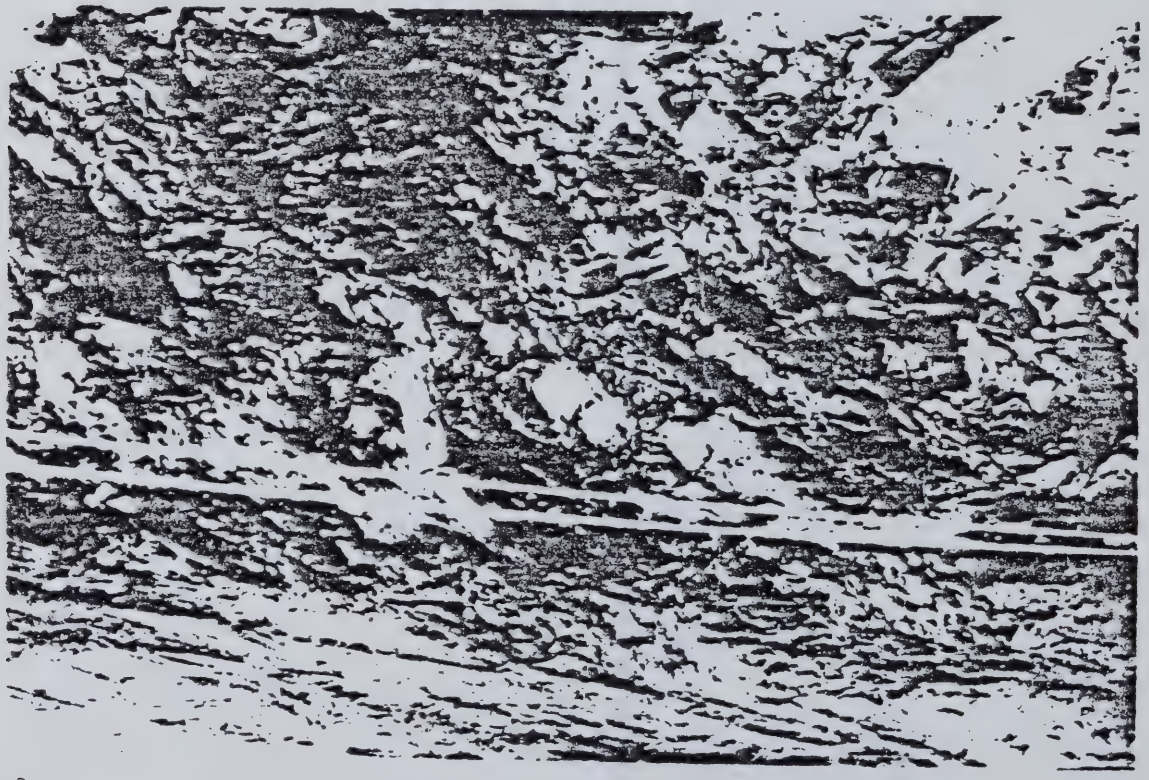
COAL

SANDY SHALE

PLATE I



A. ROOF FALL IN BAD TOP AREA, SHANNON BRANCH MINE



B. CLOSE UP OF SLICKENSIDED SHALE IN BAD TOP AREA SHANNON BRANCH MINE

down to or into the coal causing considerable problems for roof bolters as well as long-wall shears and plows. The top in this area is now being supported with trusses and bolts.

In the good top area, the roof is consistent both laterally and vertically and composed of a coarsening upward sequence of shale with coal streaks and layers of plant debris, which grades upward to sandy shale for about 25 feet above the coal. There is abundant plant debris with a moderate number of kettle bottoms in the sandy shale layer. No particular problems were encountered during the driving of these entries except where old fallen works were driven through.

1.3.3.3 DESCRIPTION OF BISHOP MINE

Coal height in Bishop mine is extraordinary - ranging in height from 35 inches to 8 feet. The mine layout is dictated by the major border fault which forms the southeastern limit of the property (Fig. 6). From northwest to southeast across the property the Pocahontas #3 seam dips gently until it approaches the border fault where the seam is folded into sharp but low amplitude rolls that parallel the fault. Directly adjacent to the fault the seam turns up to 90^{o}, apparently as a consequence of drag.

Roof rocks in the good top area in Bishop mine, are a hard thick sandstone which is typical of the western portion of the mine (Fig. 7). Sedimentary structures in this sandstone include cut and fill cross-bedding scour, sole marks and groove casts. The only falls in this area are associated with broad flat horseback type features that extend downward 2 to 6 inches from the roof.

In the bad top area roof rocks are quite different from the good top area (see Plate IIB). A thin 5 to 8 foot often rooted, flazered, medium-grained sandstone undulates gently over the coal seam which is approximately 8 feet thick. The interval between the sandstone and the coal ranges between 0 to 4 feet. Veneering the underside of the sandstone is a root penetrated, slickensided fine-grained rock which continually spalls. Kettle bottoms, large roots and coal spars are also commonly encountered. This rock type can barely be contained with straps, headers, and bolts and consequently, is a continuing problem. Above the sandstone which overlies this shale are thin layers of shale and coal. When the sandstone is thin, the roof breaks up to the level of the shale and coal causing very serious roof problems.

1.3.3.4 DESCRIPTION OF KEYSTONE II MINE

Coal height at Keystone II ranges from 30 inches to approximately 5 feet. The mine is structurally located on the southeastern limb of a broad gentle anticline and consequently the seam dips gently to the southeast.

The bad top area in Keystone II is located in the southern half of the mine (Fig. 8). Between the top of the Pocahontas #3 seam and the rider seam which is about 10 to 20 feet above the main

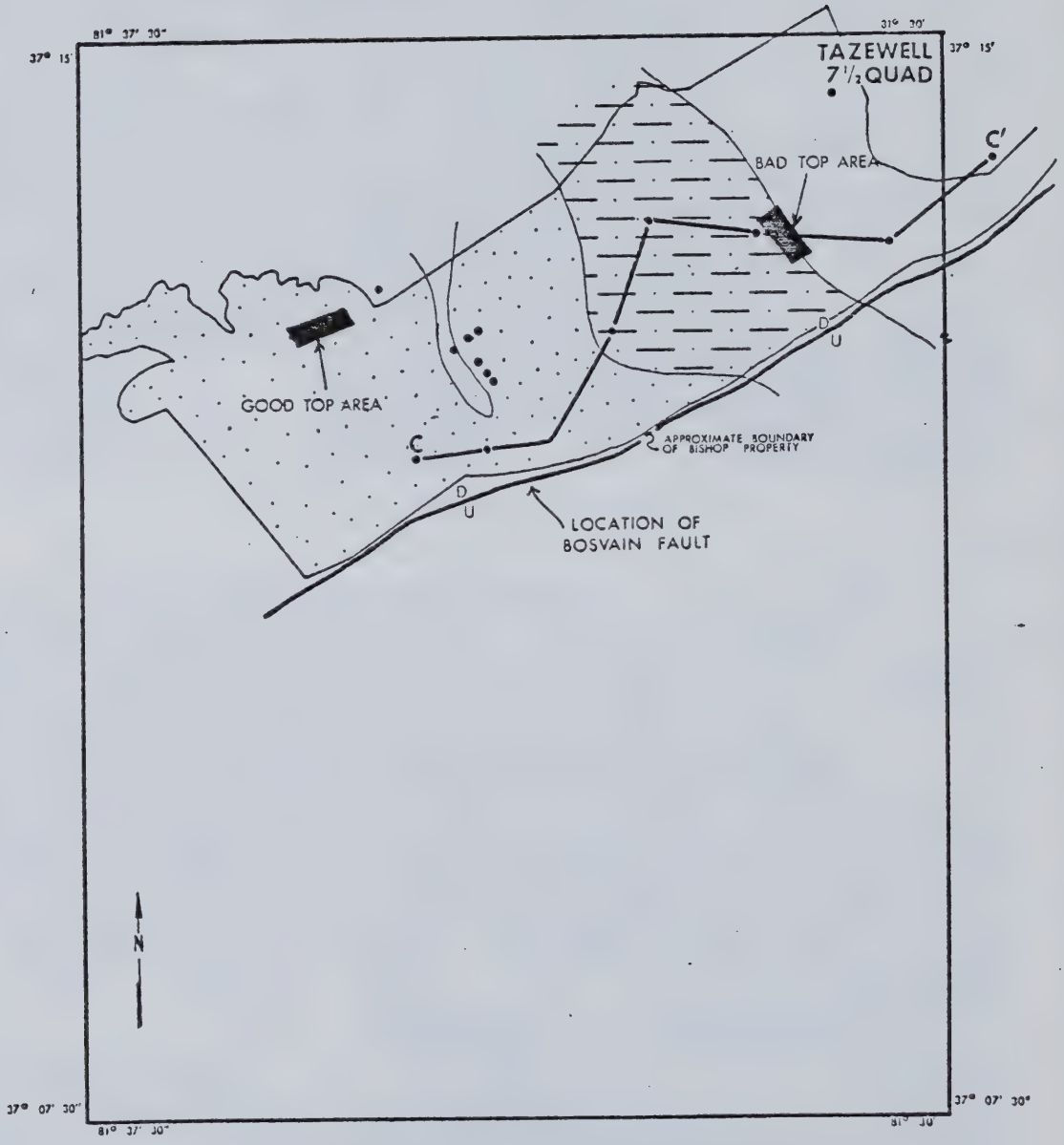


FIGURE 6 ROOF ROCK MAP OF BISHOP MINE CONSOLIDATION COAL CO.
(SEE FIG. 1 FOR LOCATION)

ROCK TYPES IN INTERVAL 20' ABOVE POCAHONTAS #3 COAL BED

0 2000 4000 6000
FEET

SANDSTONE

SANDY SHALE

SANDSTONE AND SHALE

CORE HOLE LOCATION

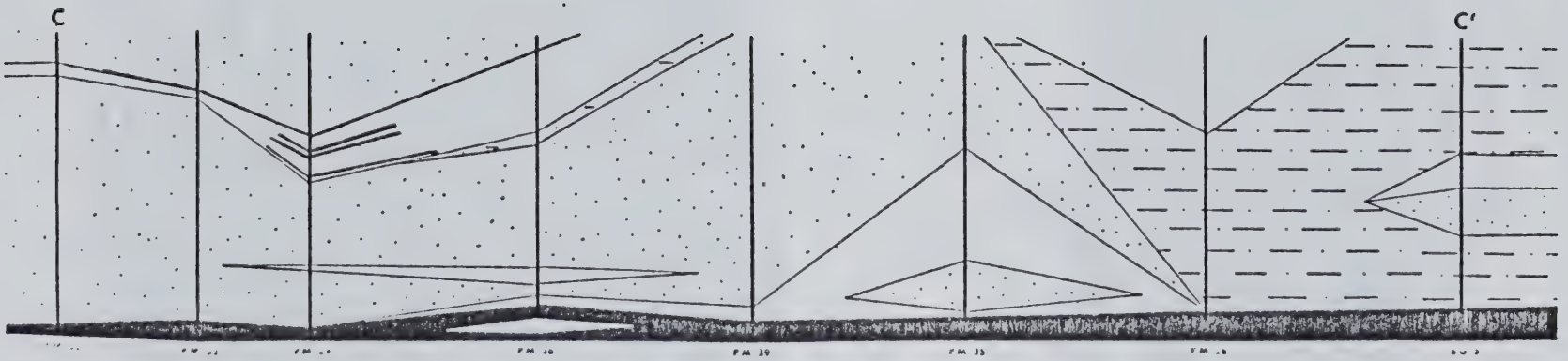
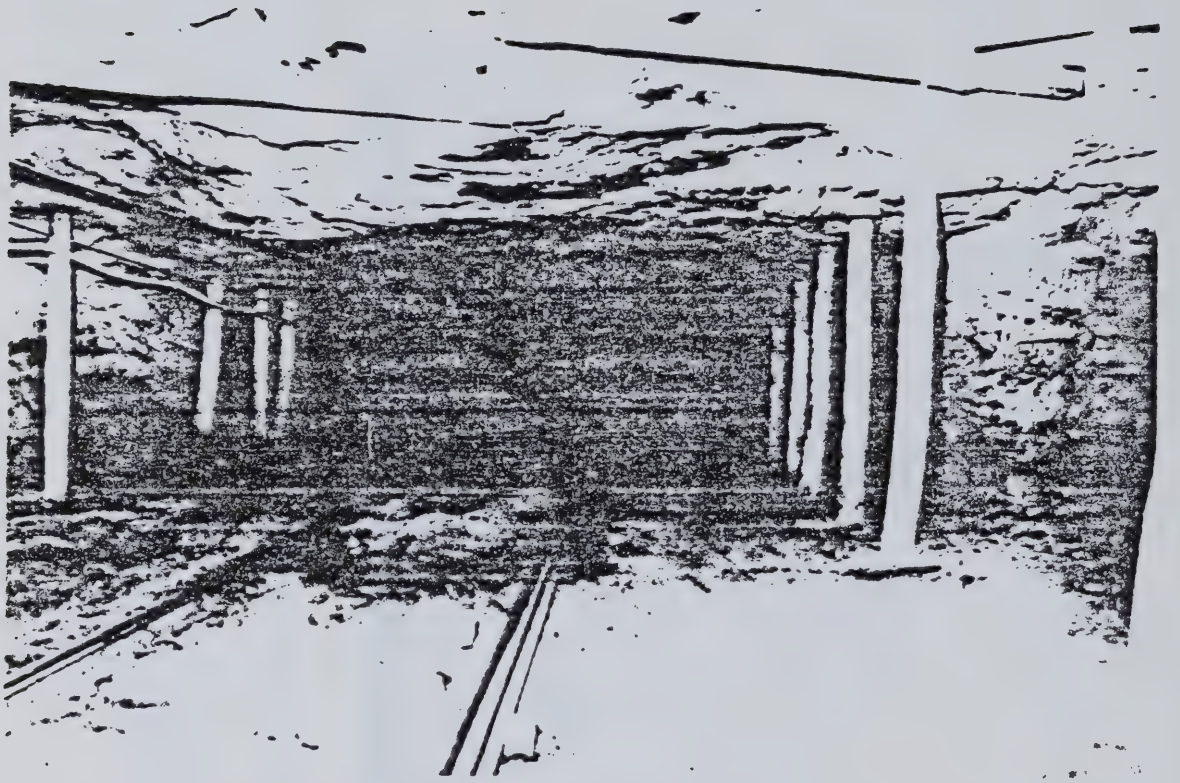


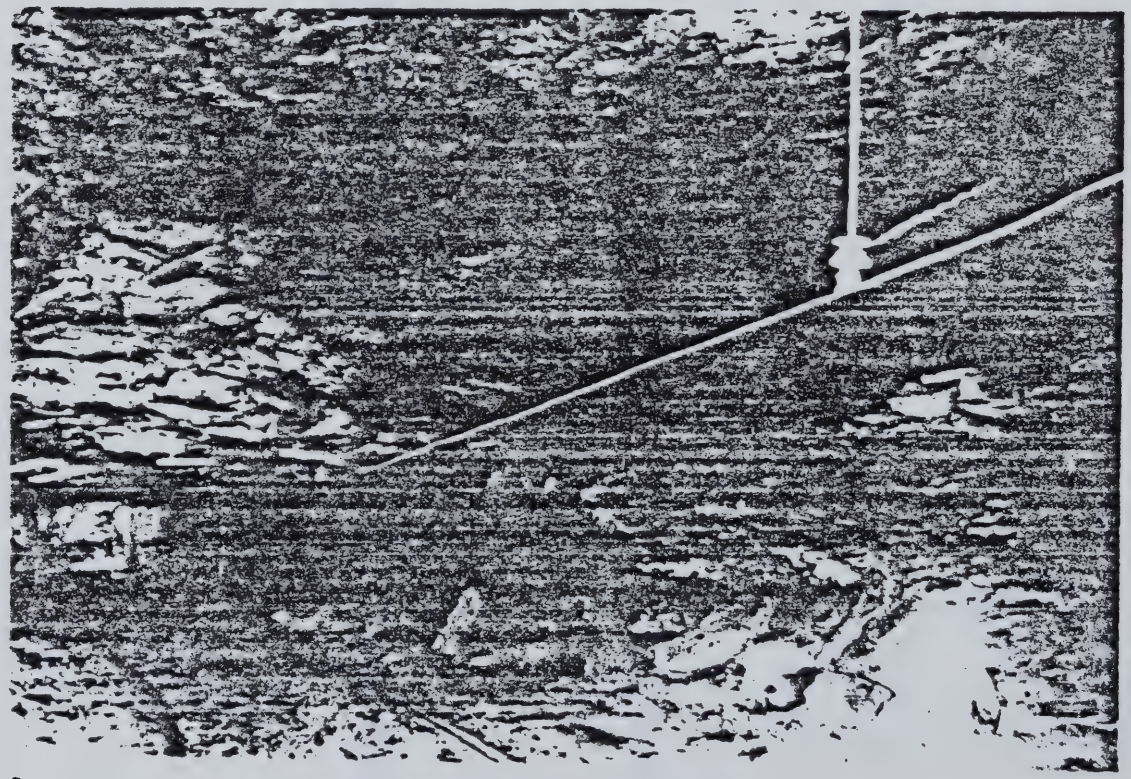
FIG. 7 CROSS SECTION ALONG LINE C-C' (FOR LOCATION SEE FIG. 6)

SANDSTONE
SHALE
SANDY SHALE
COAL

PLATE II



A. ROOF OF GOOD TOP AREA, BISHOP MINE



B. ROOF FALL IN BAD TOP AREA, BISHOP MINE

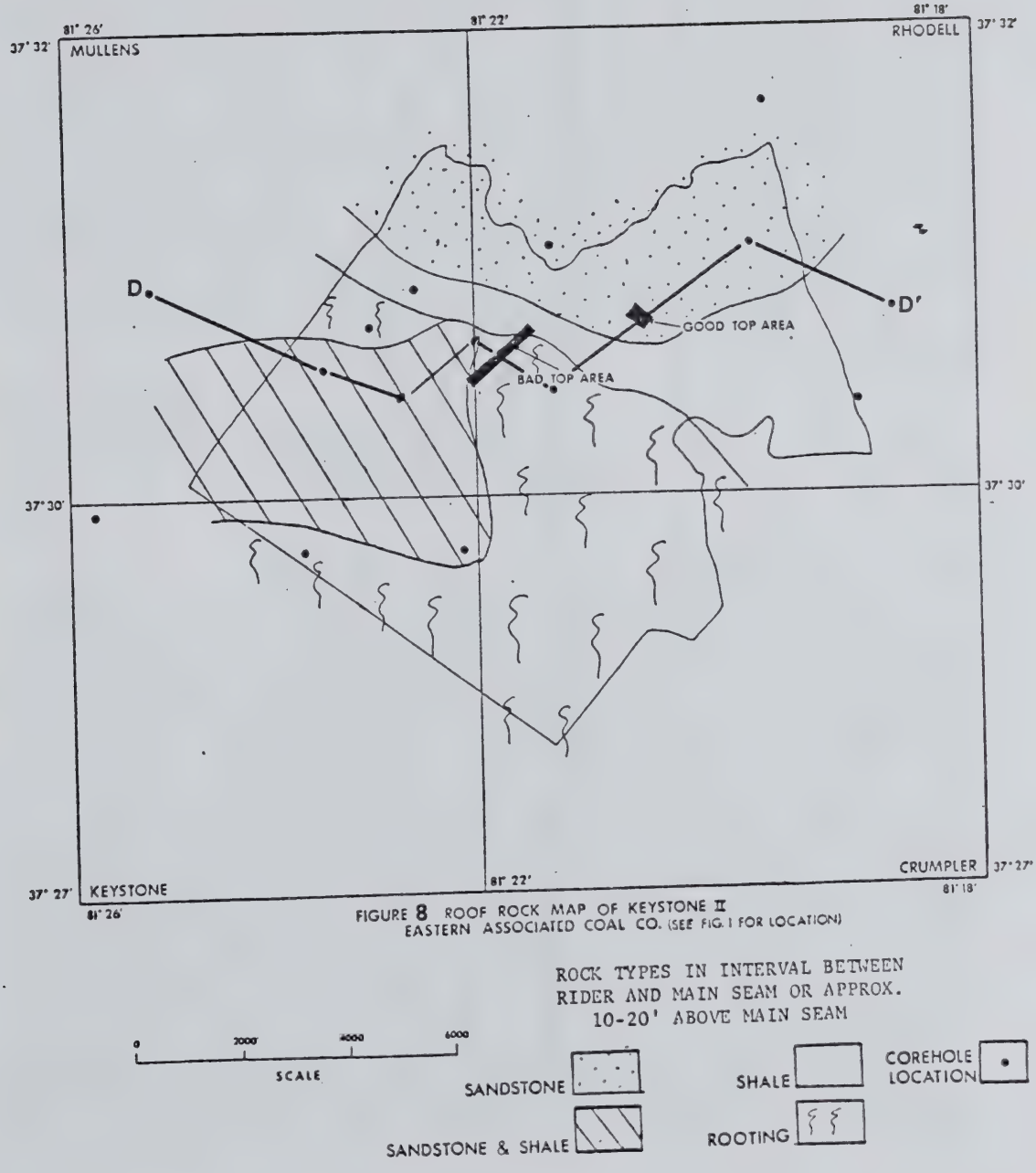


FIGURE 8 ROOF ROCK MAP OF KEYSTONE II
EASTERN ASSOCIATED COAL CO. (SEE FIG. 1 FOR LOCATION)

seam, there are three major fine-grained rock types. (Fig. 9) The first is a root penetrated fine-grained rock sometimes designated shale by drillers but more properly it is called a silty seatearth. It is characterized by root traces and slickensides and has little physical strength. Miners often refer to it as "clod rock" because it falls in big chunks which appear similar to clods of earth in a freshly plowed field. In the roof, it is difficult to hold and extremely dangerous (Plate IIIB). However, some success has been obtained by using resin bolts.

The second type of rock found between the main seam and the rider is a sequence consisting of seatearth underlain by wide, flat bodies of thinly bedded sandstone. The sandstone lenses are on the order of hundreds of feet long and wide and up to 6 feet thick. Where the lens shaped bodies of sandstone are present, the roof is relatively strong but where the seatearth is present in abundance, serious roof problems occur. Linear sandstone channels within this seatearth have a pronounced northwest-southeast orientation. Where these channels cut through the rider and come close to the coal, roof conditions deteriorate rapidly as the enclosing seatearth falls away making the rock surrounding the sandstone difficult to support. The orientation of the sandstone channels and the orientation of fractures in the rooted shale have a similar trend and are probably related.

The good top area of Keystone II is a solid, hard sandstone (Plate IIIA) which is highly crossbedded. In this and other areas of good top, bolting is not needed. On the eastern border of the good top area, the roof rock type changes abruptly to a dark grey shale and several falls do occur at this contact.

1.3.3.5 DESCRIPTION OF MACALPIN - EAST GULF MINE

Figure 10 shows the distribution of rock types up to 10 feet above the Pocahontas #3 seam on the north and southern portions of the property. The Pocahontas #3 seam dips gently northwestward across the property. Various small flexures and troughs are superimposed over this general trend. Coal thickness ranges from 36 to 48 inches.

The roof in the good top area is sandstone only in main entries (Plate IV-A). In other entries, a one-half inch layer of shale underlying the sandstone was left in place. Kettlebottoms and tree bark remains are abundant in this thin veneer of shale. Kettlebottoms are more numerous here than in the other mines and elongate pieces of tree bark seem to have a northeast-southwest orientation. In a few areas, a thin layer of hard, durable "burnt" coal was left on the roof. For the most part, the good top area consists of solid sandstone.

The bad top area consists of a coarsening upward sequence of carbonaceous shale, thin rider coal, sandy shale, flazered sandstone, and greywacke sandstone. The latter in some places cuts through the underlying rock down to the top of the coal. Falls generally occur

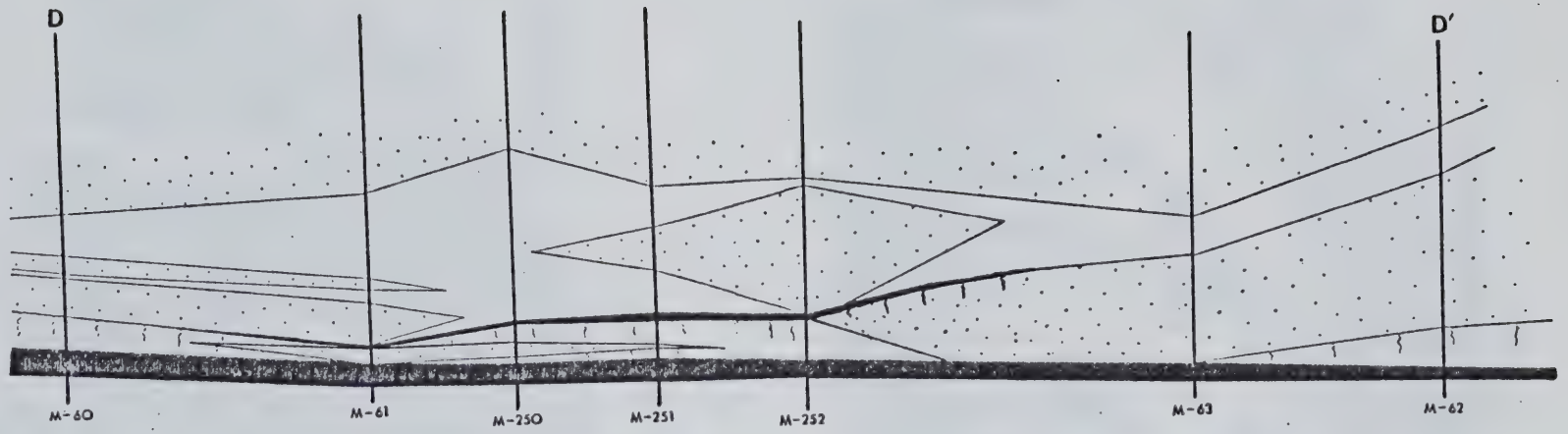
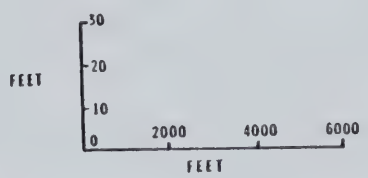


FIG. 9 CROSS SECTION ALONG LINE D-D' (FOR LOCATION SEE FIG. 8)

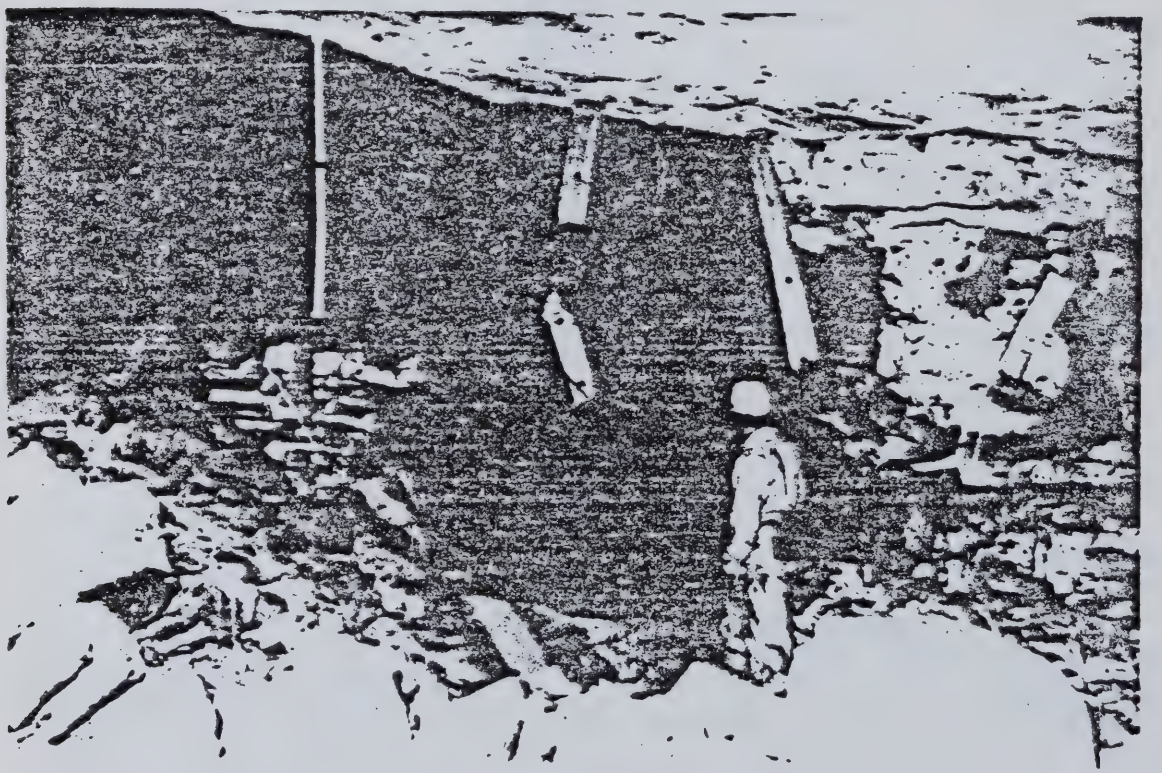


SANDSTONE SHALE

ROOTING COAL

PLATE III

A. ROOF AND DRILL SITE OF GOOD TOP AREA, KEYSTONE II



B. ROOF FALL IN BAD TOP AREA, KEYSTONE II
NOTE RIDER IN UPPER RIGHT CORNER

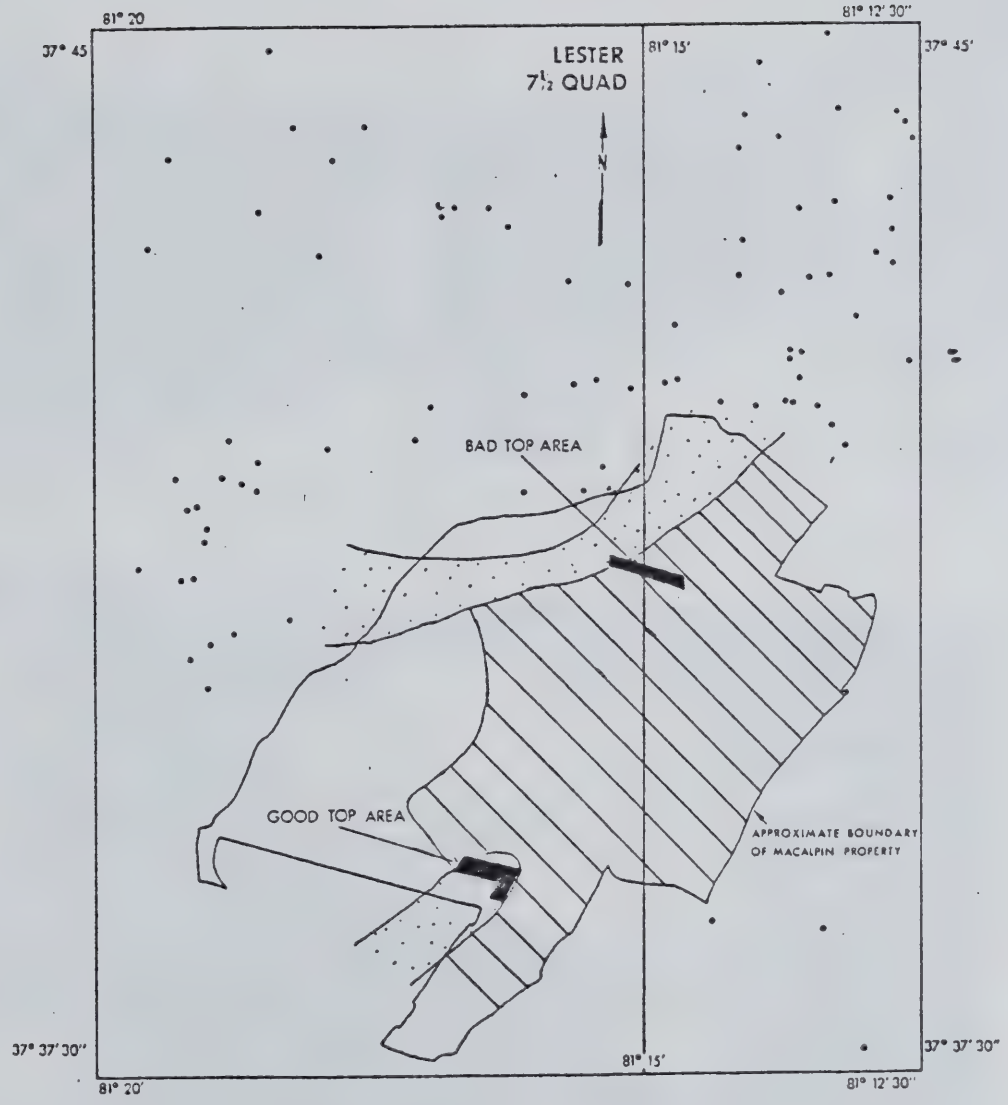
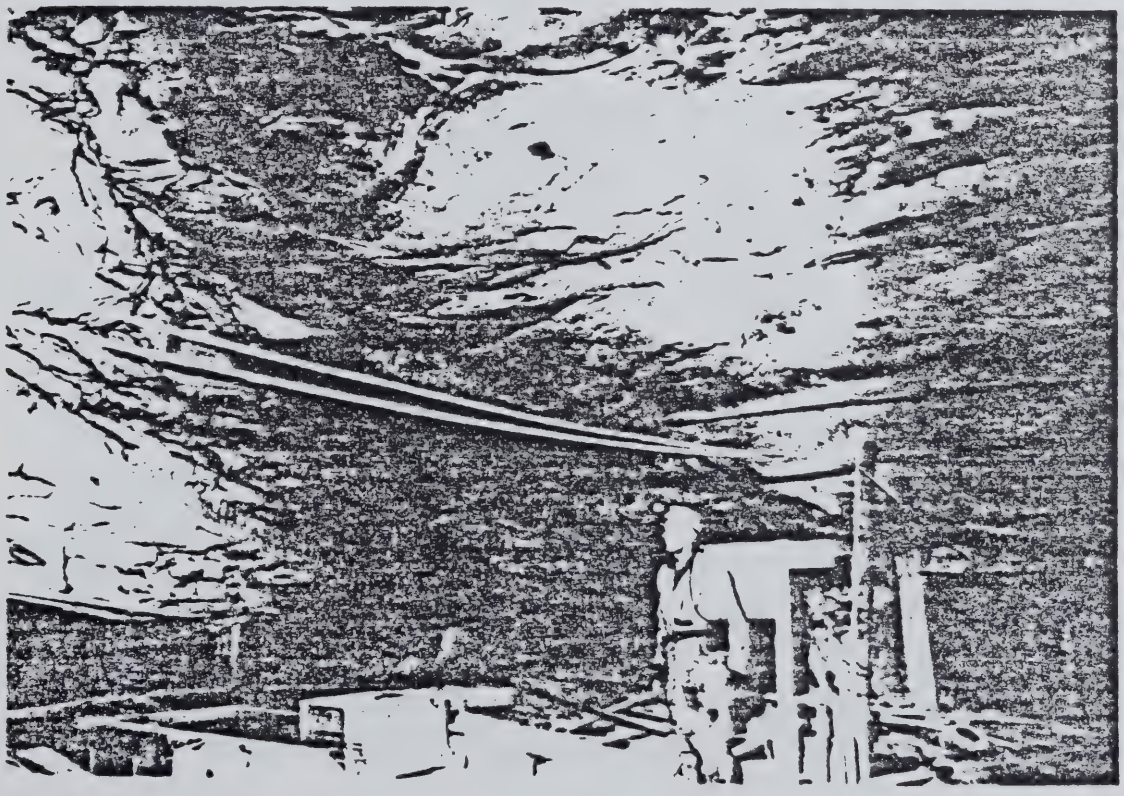


FIGURE 10 ROOF ROCK MAP OF MACALPIN, EAST-GULF MINE
WESTMORELAND COAL COMPANY (SEE FIG 1 FOR LOCATION)

PLATE IV

A. ROOF OF GOOD TOP AREA, EAST GULF MINE
NOTE KETTLE BOTTOM, UPPER RIGHT



B. ROOF FALL IN BAD TOP AREA, MACALPIN MINE 37

where greywacke sandstone body rises from or descends to the coal and/or where the finer-grained sediments are disturbed or contorted by local compaction features (Plate IV-B). The roof in the bad top area, shows abundant kettlebottoms and tree bark where the roof has not fallen. Tree bark in this area seems to have a general east-west orientation.

1.3.4 SUMMARY OF PHASE II RESULTS

Because certain geologic phenomena were associated with areas defined as good and bad top, it was possible to make some qualitative observations about geologic factors which contribute to roof instability. In addition, it was possible to emperically catagorize geologic phenomena according to its effect on the roof of the mines, and to indicate that specific rock types, rock sequences and other phenomena such as scouring and slickensiding either were generally associated with good or bad roof conditions. However, it should be emphasized that tectonic effects, residual stress affects and joint patterns were not objectively tested. On the other hand when such phenomena were obvious and their effects evident, their presence was noted. These observations, above all, show that various stresses and resulting joints or rock failures effect different kinds of rock in different ways. For example, coarse-grained rocks are generally stronger and can support more weight and stress than fine-grained rocks. In addition, sandstones up to their point of failure appear to hold and transmit stress better than shales which usually joint and fracture when stressed. Finally, contacts between rock types are often weaker, and become points or planes of initial rock failure.

1.3.4.1 EFFECT OF ROCK TYPES

The kinds of rock types generally found above the Pocahontas #3 vary considerably from hard brittle orthoquartzite sandstone and greywacke pebble sandstones to fine-grained shale and seatearth.

As a rule, grey sandstone in thicknesses greater than 15 feet which are within bolting distance of the coal make excellent top. In most cases little support is necessary. At East Gulf, for example, grey cross-bedded sandstone approximately 30 feet thick lies directly on the coal seam. There, double width track entries have been standing for many years without bolting and only occasional timbers provide support (see Plate IV-A). On the northern side of Keystone II a similar sandstone lies directly on the coal and many acres of entries and cross-cuts are unbolted.

On the other hand, certain kinds of sandstone are rather susceptible to roof fall. Probably the most potentially hazardous are hard crystallized sandstones (recrystallized orthoquartzites). These rocks are so hard that drilling roof bolt holes may be prohibitively expensive. Moreover, when these rocks are stressed, they become jointed and crushed. This has occurred on the west side of Virginia Pocahontas #3 mine causing falls of sufficient size that the area was closed and circumnavigated. Moreover, recrystallized sandstone generates enough heat on impact of a fall to cause ignition in

gaseous atmospheres. Such an event was experienced in Virginia Pocahontas #3 during 1975.

Another potentially hazardous rock type is grey sandstone with prominent high-angle cross-bedding, cut and fill features, and lag gravels. In parts of Macalpin, falls composed of this kind of rock predominate, especially in mine intersections. In Shannon Branch large wedges of slumped shaly deposits and sizeable pieces of shale and coal debris are interbedded with pebbly grey sandstone. Where mining was attempted, more than a 1000 feet of entry had to be abandoned.

Another common variety of sandstone is stack rock. It is characterized by very thin flat beds of hard grey sandstone interbedded with thinner beds of coarse mica or coaly material. The repetitive sequence of this type breaks in thin layers like the pages of a book. This is common in the Virginia Pocahontas mines in Buchanan County, Virgina where falls tend to break down the middle of entries or along the ribs.

Sandy shale is a rock type which makes excellent top, especially when found in a coarsening upward sequence. Such is the case in the southern part of Virginia Pocahontas #3 mine. However, where sequences of sandy shale exceed 25 feet in thickness, they break easily and are susceptible to jointing. Studies of joint orientation and butt and cleat would be appropriate in such rock types since joint patterns may have some bearing on roof conditions.

Fine grained rocks, shales, and fire clays, are not abundant roof materials in the Pocahontas #3 mines. They are composed of fine-grained quartz grains embedded in a mass of micas and clays. The latter materials are physically weak and wetting further reduces their strength. When continuously wetted they deteriorate into mud or when wetted and dried tend to separate and fall to pieces. The most common of the fine-grained rocks is dark gray shale, which continuously spalls with small pieces falling out between bolts. When such rocks are found in sequences greater than 25 feet they are highly susceptible to jointing and breaking. Usually they break straight up ribs generating high falls, often several breaks long.

Fire clays and seatearths, another variety of fine grained rock, also exhibit this weathering property, but in addition, many fire clays are cut by prominent slickenside planes which further reduce their capcity for roof support. Such materials should never be used over main entries as they are a continuing source of trouble. Such difficulties were experienced in Keystone II (Plate III).

Two other less common types of fine grained rock are black carbonaceous shale and "rashy" shale (shale with coal streaks). Black carbonaceous shale is a homogeneous massive rock. It is very brittle and falls out in large and small blocks. It is often referred to as "cube" rock. Ordinarily, over the Pocahontas #3 seam it is found only in thin lenses such as in Macalpin or East Gulf. However, it is common in other seams of the region and in thick, 20 foot lens-shaped deposits. It is considered extremely dangerous and difficult to support.

Rashy shale is common as thin deposits directly above the Pocahontas #3. It is common to mine the "rash" along with the coal because it normally spalls and flakes causing a debris problem. However,

if the rashy zone becomes thick (3 feet or more) it is, like "cube rock", considered dangerous and difficult to hold.

Rider coals, those thin coal seams found between two to thirty feet above a main seam are generally considered dangerous. However, when a rider is directly overlain by a thick shale or seatearth it can protect the top from weathering, thus reducing falls drastically. If a rider is left in place and the bolt anchored in a good strong overlying rock such as sandy shale or sandstone, riders generally are good top. On the other hand when riders are six feet or higher above a fining upward sequence, or above a good thickness of jointed or fractured shale or seatearth there will be abundant falls, as was encountered in Keystone II (see Plate III).

1.3.4.2 EFFECT OF ROCK SEQUENCE

Sequences of rock types up to 60 feet above the Pocahontas #3 seam can be categorized into three major groups - 1) homogeneous rock bodies, 2) coarsening upward sequences or 3) fining upward sequences. These sequences are made up of the major rock types that have been previously described.

Homogeneous rock bodies behave most predictably for roof support purposes. If the unit is thick and made entirely of sandstone it will usually be excellent top that falls infrequently. Falls that do occur in thick bodies of sandstone arch out quickly and usually are not large. Thick bodies of shale and sandy shale are another matter. When sequences of homogeneous shale or sandy shale become excessively thick (greater than 40 feet) long high falls can occur which are extremely difficult to control. Moreover, these rock types are especially susceptible to jointing and fracturing, enhancing the roof fall hazard. Thinner sequences however (less than 20 feet) make excellent top either for advance or retreat mining.

Coarsening-upward rock sequences generally make good top. As a sequence changes from shaley to sandier rock types, the strength of rocks increase. Lower layers must only support themselves or be bound together by bolts forming a bridge. Higher layers are stronger and usually above stress arches. For roof bolted entries this is the ideal situation.

In contrast, fining upward sequences can be dangerous, depending on the thickness of the sequence and the kind of rock types involved. For example, a 15 foot sequence which fines upward from sandstone to shale with a 6 inch layer of coal at the top will be very difficult to support, especially if the sandstone is thin (less than 5 feet thick) or is discontinuous. The entire sequence will probably break along ribs and fall up to the rider. Roof bolt systems work poorly in this situation because there are no solid anchor points and lower rock layers are not strong enough to support upper weaker layers. However, some success has been achieved with trusses anchored into the ribs above the seam.

1.3.4.3 EFFECT OF CHANNEL SCOURING

Other geologic phenomena which seem to contribute to major areas of bad top are sandstone channel scours.

Sandstone scours are linear trough shaped features that usually cut into shales above the Pocahontas #3. When found in the coal they are called "rolls" or "wants". Naturally, such phenomena are difficult to mine through since sandstone filling the trough is usually hard to cut with mining equipment. Often the contacts between the scours and adjoining shales are slicked and very weak, causing considerable roof problems as is the case in Macalpin. In Shannon Branch the longwall hit a sandstone roll cut into the coal and the scour ran diagonally across the mining face. The cutting mechanism on the long wall was not able to cut through the sandstone and because progress was slow, the jacks began to take weight. The jacks finally became so tightly wedged that the longwall was removed and almost an entire panel of coal was abandoned.

1.3.4.4 EFFECT OF SLICKENSIDES

Slickenside surfaces occur in nearly all rock types and almost always produce poor roof conditions. Most notably, bad top in Bishop, Shannon Branch and Macalpin are produced by slickensides. As observed in these mines and others in the area, however, slickensides present a complex problem as they arise in a number of different ways. In the case of Bishop, slickensides which adjoin the major fault zone are clearly the result of major mountain building forces. In other cases slickensiding seems to have arisen before sediments become consolidated. The clearest example are "kettle bottoms" which are sandstone or shale filled stumps extending upward from the top of the coal seam into the roof of the mine. The sides of many of these kettle bottoms shows evidence of slicking which can be more readily related to compaction and dewatering of sediment than to major tectonic forces. In cases of slickensiding on basal contacts of channel sandstone scours in shale such as Macalpin, a similar explanation can be advanced. At the time the sand was deposited on the scoured surface of the mud (shale) neither sand or mud was firmly consolidated. As more sand was deposited and compaction began, the mud compacted to a greater degree than the sand and, as the relatively uncompactable sand in the scour channel was pushed into the mud, shear developed on the sand-mud contact producing a slicked surface.

The most obvious examples of slickenside development in poorly consolidated sediment are observed in the Shannon Branch Mine. Here great blocks of strata (including the rider coal) are upturned and tilted in the same manner as is found in slump deposits on modern stream banks. The contacts between tilted blocks both in the rocks and in modern deposits are highly polished and the blocks themselves are cut by numerous slicked surfaces.

Finally there are the slickensided surfaces that cross-cut seatearths. The origin of these slick planes is not at all clear but such features have been observed in poorly consolidated root penetrated sediments in the alluvial and deltaic deposits of the Mississippi River and may be the result of compaction and dewatering of soils.

2.0 PHASE III - ASSOCIATION OF GEOLOGICAL FACTORS AND ROOF QUALITY IN FIVE UNDERGROUND MINES IN BUCHANAN COUNTY, VIRGINIA

2.1 INTRODUCTION

One of the principle objectives of Phase I and II was to obtain a complete spectrum of mining and geological attributes related to roof falls in the Pocahontas #3 coal seam in southern West Virginia and southwest Virginia. At the outset of Phase I, data was gathered in the form of answers to an extensive questionnaire probing mining, geological and roof characteristics in over 40 mines. This data was then assembled, analyzed and catagorized for the purpose of selection of specific underground study sites in Phase II. The main body of Phase II was the description of mining and geological conditions of good and bad top areas in five mines selected to show the greatest amount of variation in roof conditions in the Pocahontas #3 seam. These studies were summarized in a subjective fashion which indicated that certain rock types, rock sequences or other lithologic attributes were seemingly associated with roof quality.

The purpose, then, of Phase III of the study of roof quality for the Pocahontas #3 seam was to establish statistical verification for the conclusion drawn in Phase II. Specifically, the objective of Phase III was to determine by a controlled series of measurements whether specific rock types, rock sequences or rock attributes could be associated with roof quality. Secondly, the study was intended to establish some measures indicating the areal extent of rocks having certain roof attributes.

2.2 SITE SELECTION

The principal factor governing selection of the site in which the study was to be made was obtaining the greatest variation in geological factors believed to influence roof quality while at the same time keeping other possible influences relatively constant. In accord with the results of Phase II, the spectrum of rock types should include gray sandstone, orthoquartzite, a number of fine grained rocks including shale and to a lesser extent fire clay or seat-earth and rider coals. These rock types should occur in sequences which 1) are essentially uniform, 2) display a coarsening upward or downward trend or 3) occur in mixed alternating sequences of coarse and fine grained rock. Finally, there should be areas of channel scour and slickensides in the roof rock. Those factors which should be constant include geologic structure, overburden thickness, surface topography, mining techniques and practices, mine layout, mining equipment, presence or absence of mining above and below, ground water conditions, age of mine and experience of mine personnel. Finally, if it is assumed that there may be some unkown factor or factors related to geographic location, a further condition is added that the mines be in close geographic proximity to one another.

Specific information concerning the precise rock type and sequence is difficult to obtain before underground inspection but examination of the questionnaire data from Phase I indicated that the cluster of five Island Creek Coal Company mines of the Pocahontas #3 seam in Buchanan County, Virginia did have thick gray sandstone top and a reasonable proportion of fine grained rocks. In addition, one of the mines, Virginia Pocahontas #3, was found during Phase II to have an orthoquartzite sandstone roof. No rider coals were reported from any of the mines but it was assumed that they could be present as very thin riders that are seldom noted by underground personnel.

In other respects these mines were admirably suited. They all occur in the same milieu of geologic structure near the major border faults that form the southern limit of the Southern Appalachian coal field and that these structures have been carefully mapped at the scale of 1:62,500 by the Virginia Geological Survey (Hinds, 1918). The mines are all very deep (on the order of 2000 feet) and hence are little effected by surface topography such as streams and valleys. The mines were all planned and operated from the same division headquarters and operational procedures are uniform throughout. Support systems are also uniform. All of the mines were reported to be relatively free of water and, because the Pocahontas #3 is the only seam in the area with major thickness and continuity, there are few if any seams mined above or below it. Finally, core hole data was relatively abundant and drilling has been monitored by the same personnel.

The five mines comprising the Virginia Pocahontas Division of Island Creek Coal Company that were selected for the measurement program are Beatrice, Virginia Pocahontas #1, Virginia Pocahontas #2, Virginia Pocahontas #3, and Virginia Pocahontas #4. Their location is shown on Figure 11.

2.3 THE MEASUREMENT PROGRAM

The measurement program had two principal objectives. The first was to develop a simple and usable system by which roof rocks could be characterized and applied throughout the entire area. The second was development of a classification of roof quality that could be uniformly used. Such goals are necessary if the resulting data is to be systematically treated and if the results are to be useful in practical situations.

2.3.1 PROCEDURES

The first step in developing a useful rock classification was obtaining all relevant core hole records from the Virginia Pocahontas division office and entering this data into a 370/168 IBM computer where the data was coded and graphic logs prepared at the vertical scale of 10 feet = one inch on a Cal Comp 563 plotter. The objective in examining these graphic plots was determination of rock character and lateral variability of strata for 50 feet overlying the mined areas

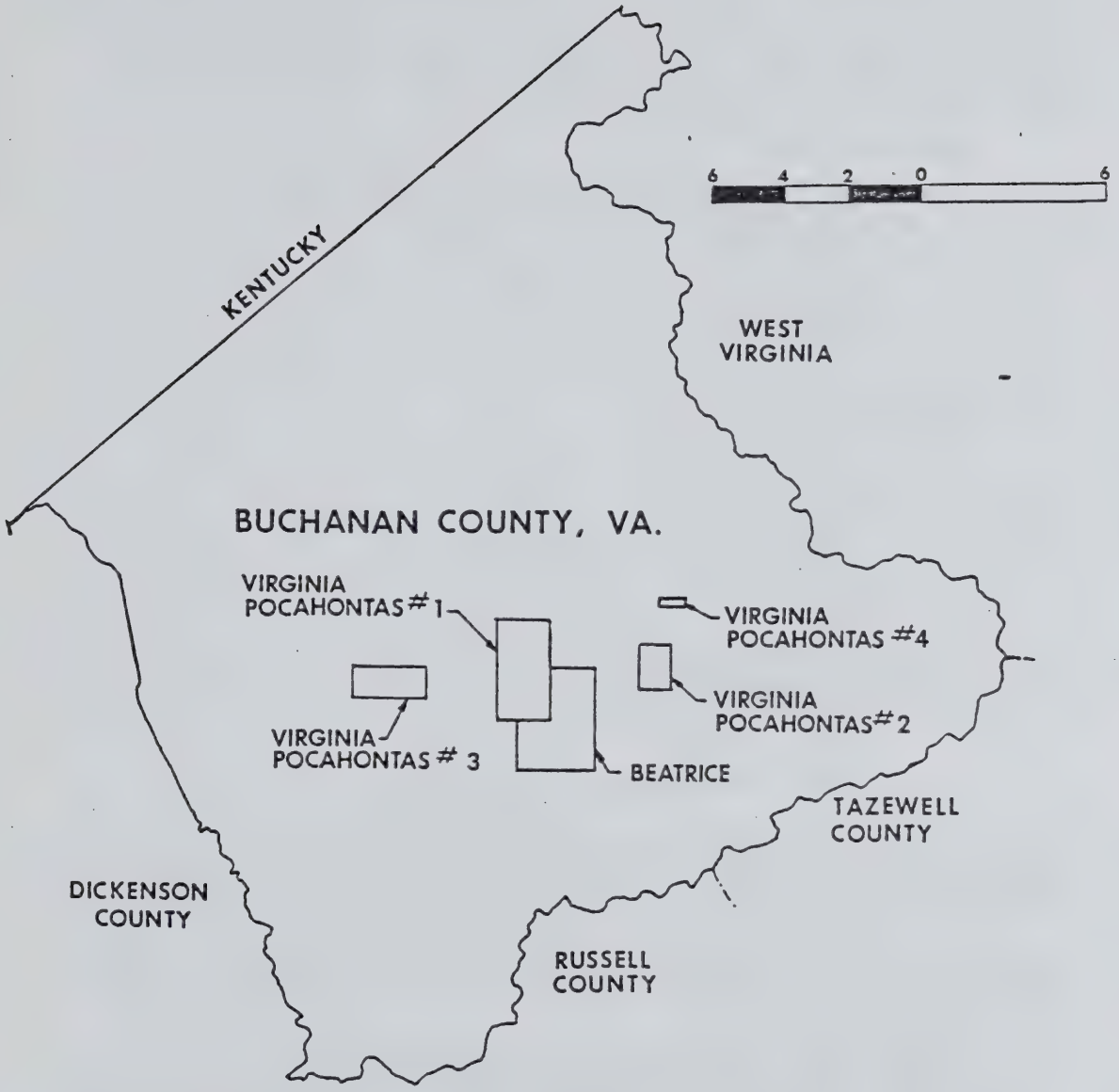


FIGURE 11 LOCATION MAP FOR ISLAND CREEK COAL COMPANY MINES, VIRGINIA POCAHONTAS DIVISION.

of Pocahontas #3 seam. Examination of these data permitted preparation of preliminary roof rock maps at the scale of 2000 feet = one inch. These data were used as a guide for the underground mapping program.

The purpose of underground study was two-fold. The first was mapping geological characteristics using the preliminary roof rock map as a base. The second was gathering data to formulate a measure of roof quality. In both cases the sampling unit area was about 10 to 20 linear feet of entry. Within such areas the following geological information was recorded.

Roof rock type:
- Graywacke sandstone or pebbly sandstone
- Orthoquartzite sandstone or pebbly sandstone
- Sandy shale
- Shale
- Seat earth
- Black shale
- Rider seams

Sedimentary structures:
- Plane lamination
- Flazer bedding
- Rippling
- Large scale cross bedding
- Slumping
- Mudflow

Features of Organic Origin:
- Root penetration
- Burrowing
- Kettle bottoms
- Large plant debris or carbonaceous strips

Special consideration was given to areas where the top had been shot or where it had fallen because it was only in such areas that rock sequences could be observed and coordinated with core hole data.

Data leading to a classification of roof quality were of two types - one a characterization of the roof itself and the other the measures that were required to hold the roof. Criteria for roof characterization were:

Presence and size of cracks or vertical separations
Presence and size of loose fragments in the roof
Presence and size of fragments lying on the floor

Criteria for judging roof quality on the basis of measures required to support the roof were:

Presence of normal bolt pattern
Presence of decreased bolt spacing or rebolting
Presence of half headers
Presence of steel straps with oblique bolting
Presence and spacing of timbers
Presence and number of cribs

Finally, it was all noted where these measures had failed and the roof had fallen.

In addition to above noted features that were used in systematically describing roof rock type and roof quality, the following mining characteristics were noted:

Entry width
Cross cut width
Pillar shape and size
Type of mining - continuous or longwall
Haulage - belt or track with features such as shot top for belt heads, bottom taken or corners removed
Direction of entry

The actual underground mapping program was carried out by two teams consisting of two men with the teams working adjoining entries One man on each team made the geological observations and the other the mining and roof quality observations. In this way, each team recorded data from between 2000 and 3000 feet of entry each day on mine maps at the scale of 20 feet = one inch. At the end of each day, the data sets were transferred to 100 feet = one inch mine maps, one for geological data and the other for mining and roof quality characteristics.

Entries to be traversed were chosen on the basis of accessibility and representations of all portions of the mine. Cross cuts were also mapped up to the stoppings. A total of 252,165 feet of entry were mapped with 57,655 feet in Beatrice, 48,485 feet in Virginia Pocahontas #1, 68,710 feet in Virginia Pocahontas #2, 56,065 feet in Virginia Pocahontas #3 and 21,250 feet in Virginia Pocahontas #4.

The raw data field sheets are too voluminous to be included in this report but are available at the Department of Geology at the University of South Carolina. Summary maps based on these data are described in sections 2.3.2.1 and 2.3.2.2.

2.3.2 RESULTS OF THE MEASUREMENT PROGRAM

The principal results of the measurement program were the classification of roof rock types and of roof quality and the preparation of maps showing their distribution.

2.3.2.1 ROOF ROCK CLASSIFICATION AND MAPS SHOWING DISTRIBUTION OF ROCK TYPES.

Classification of roof rock types and maps showing their distribution were derived both from the underground mapping program and from core hole data. Early in the investigation it was determined that some of the fine grained rock types found in other Pocahontas #3 mines were virtually absent in the Island Creek mines. These were black shale, seat earth and coal riders. Such rocks were present in a few places but were generally too thin or limited in areal distribution to appear on most maps. Of similar very minor occurrence were slumps mudflows and major slickenside areas. The latter were, however, present on some channel scours at the contact of thick sandstones with other rock types but these features too occupied only limited areas.

In order to develop a uniform roof rock classification that would be applicable to core hole data, and could be uniformly applied to the underground observations, it was concluded that the most suitable scheme should include the major easily recognizable rock types - gray sandstone, orthoquartzite sandstone and shale (including sandy shale) and their combinations in sequence in a 40 foot interval above the coal seam. Both on the basis of core hole data and underground observation the principal modes of occurrence seemed to be:

Thick sandstone
Thick orthoquartzite sandstone
Low splay deposits
High splay deposits
Thick shale

Thick sandstone is defined as a solid massive sandstone occupying the entire 40 foot interval upward from the top of the coal seam. The lower three feet of these sandstones have stringers of ironstone pebbles, shale clasts and coaly strips and are strongly cross bedded. Some limited bore hole data indicates that they become finer grained upward.

Thick orthoquartzite sandstone has the same general form as thick sandstone except that the grains are all quartz cemented with silica and the pebbles in the basal parts are dominated by quartz with fewer ironstones and shale clasts than thick sandstone. Probably because these orthoquartzites are composed almost entirely of quartz, a very brittle material, they are very strongly jointed. Both thick sandstone and thick orthoquartzite sandstone sequences are believed to be channel deposits. The gray sandstone, however, are probably fluvio-deltaic deposits whereas the orthoquartzite sandstone may represent tidal channel fill or tidal deltas.

High splay and low splay deposits consist of sandstone units with shale above or below. The sandstone units range in thickness from 1 to 39 feet. The designatation "High Splay" and "Low Splay" are genetic terms indicating the position of the sandstone body in the sequence. Where the sandstone lies within eight feet of the top of the coal seam, the deposit is designated "low splay" indicating that the channel from which the sand was derived ejected its material early in its evolution and deposited sand directly upon thin mud (shale) overlying the buried peat swamp. In the "high splay" deposits, sandstones are greater than eight but less than 30 feet above the top of the seam and formed at a later stage after substantial amounts of mud (shale) had covered the coal and the sand channel system was better developed.

Thick shales are sequences composed of shale or sandy shale and occupy a 30 foot interval above the Pocahontas #3 seam. The lower part of the sequence is composed of fine grained shale with some carbonaceous plant debris and some core holes indicate that the sequence becomes coarser upward by the addition of thin laminations of sandstone (flat or rippled) in the shaley matrix.

The areal distribution of these five types of rock sequences as determined by core hole and underground mapping is shown on figures 12, 14, 16, 18 and 20, and a synthesis of lateral relationships is shown on figure 22. As shown on figure 22, high splay and low splay deposits are generally found only adjoining thick sandstone and they, in turn, most often grade laterally into thick shale. In addition, the length of the contact of rock type with the coal on figure 22 is in proportion to its occurrence within the five mines. The proportions on this figure are believed to be substantially correct except in the case of high splays which can be detected only from core hole data or where the top has been cut or has fallen down.

2.3.2.2 ROOF QUALITY CLASSIFICATION AND MAPS SHOWING DISTRIBUTION OF ROOF QUALITY

The categorization of roof quality is not so complex as that of rock type as relatively little inference is required; the criteria, the quality of the top and character of support are readily observed.

Although it is abundantly clear that the attributes of roof quality are continuous variables, attempts at quantitative measurement proved to be too time consuming relative to probable gains in precision. Therefore, a qualitative classification was developed with four groups - "good", "moderate", "bad" and "fallen" - emphasizing characteristics of the top. These are described below.

Good Top is defined as that roof which is smooth and clean with no cracks and only minor spalling. Support consists of bolts arranged in a standard pattern with no apparent replacement or supplement.

Moderate Top includes roof that is rough appearing with some loose pieces about a foot wide. Some cracks and vertical separations are present but additional support by extra bolts, half headers or an occasional timber or crib has contained the problem.

Bad Top is defined as being composed of rough, broken material with numerous fragments in excess of a foot in width. Cracks and vertical separations are abundant and the roof is barely contained by extensive cribbing, extra timbers, or steel straps held by oblique bolts.

Fallen Top is the worst category where measures previously described have failed and falls ranging from two to 30 feet have been observed. Both fallen and cleaned up areas are included in this group.

The areal distribution of each of these four categories of top is shown on figure 13, 15, 17, 19 and 21. The proportions of each type across all mines are respectively - good 64%, moderate 20%, bad 13%, and fallen 3%.

2.4 THE ANALYSIS PROGRAM

The primary objective of the analysis program was to determine, using the data acquired during the measurement program (Section 2.3), whether an association could be established between the type or rock sequence overlying the Pocahontas #3 seam and the quality of the roof. Contingent upon an association being established, the secondary objective is determining whether the lengths of continuous entry of

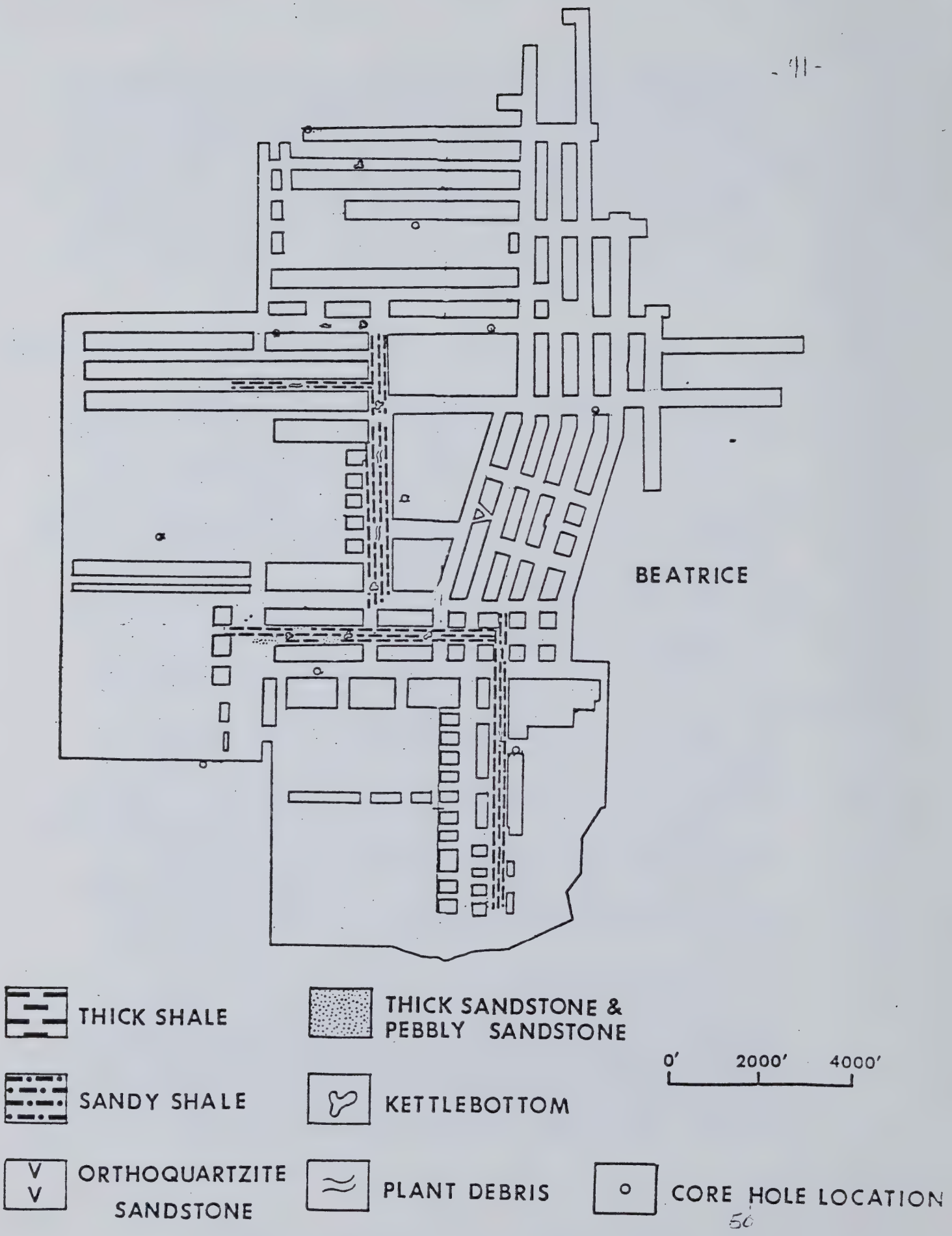


FIGURE 12 ROCK TYPES IN THE BEATRICE MINE.

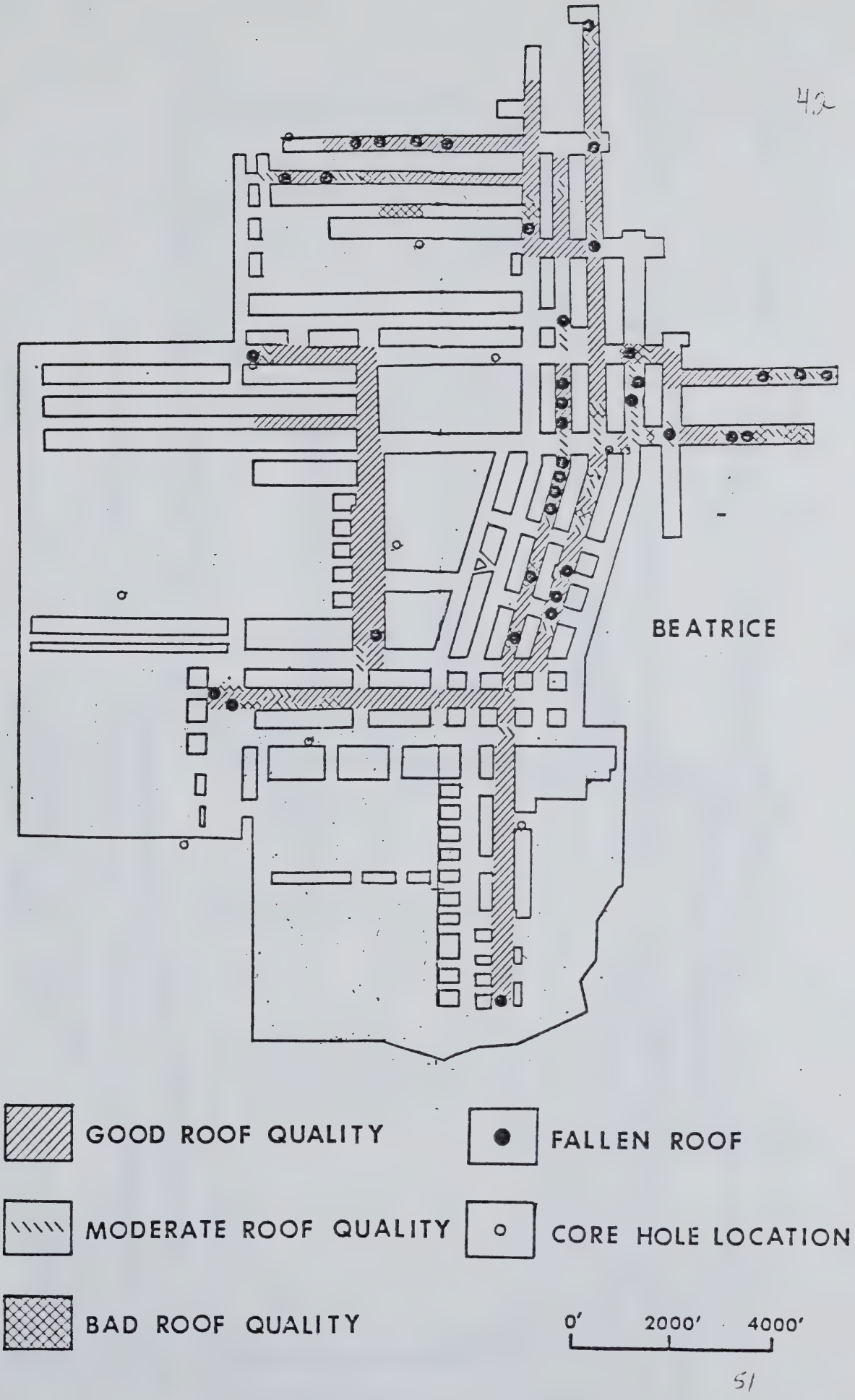


FIGURE 13 ROOF QUALITY IN THE BEATRICE MINE.

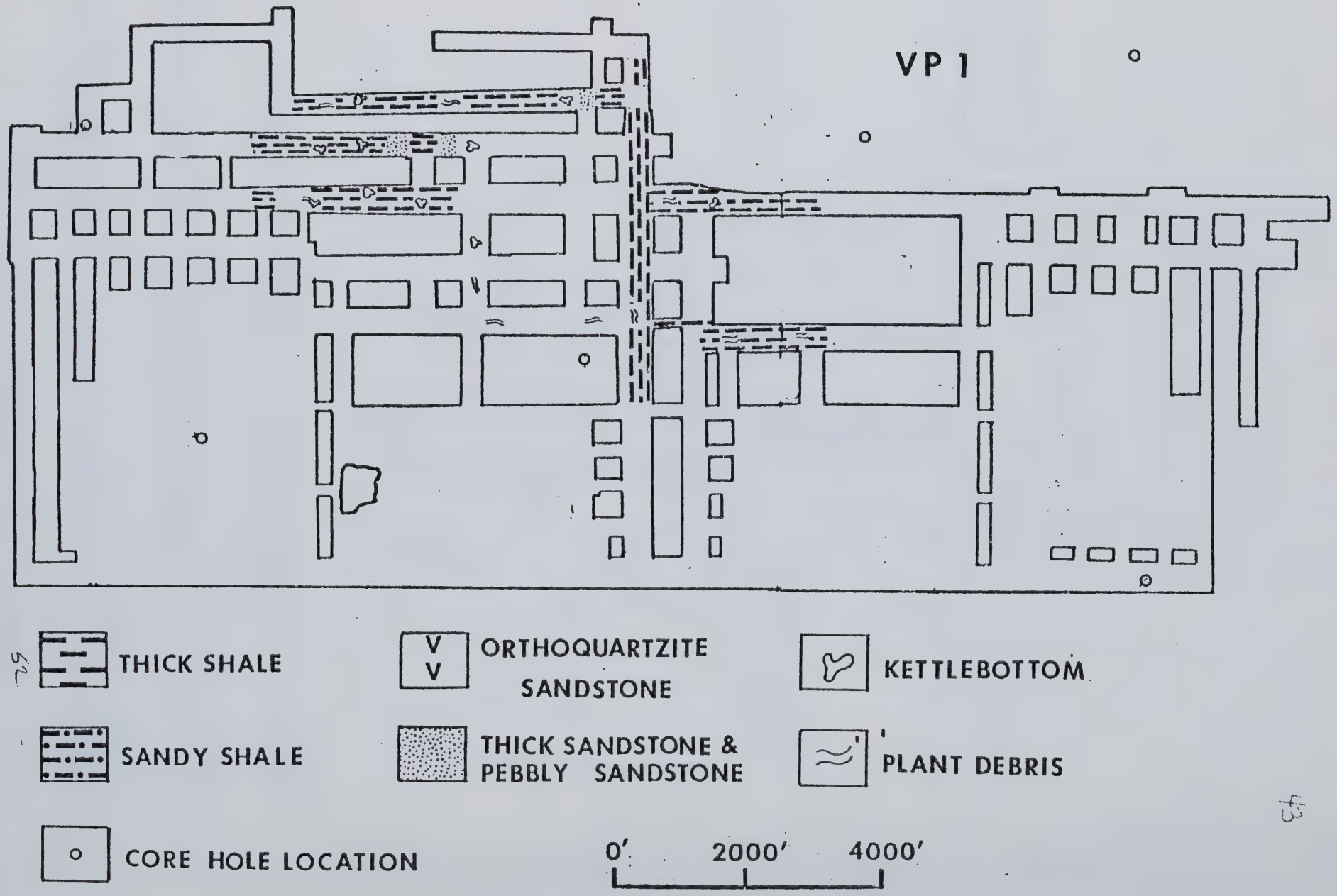


FIGURE 14 ROCK TYPES IN THE VIRGINIA POCAHONTAS #1 MINE.

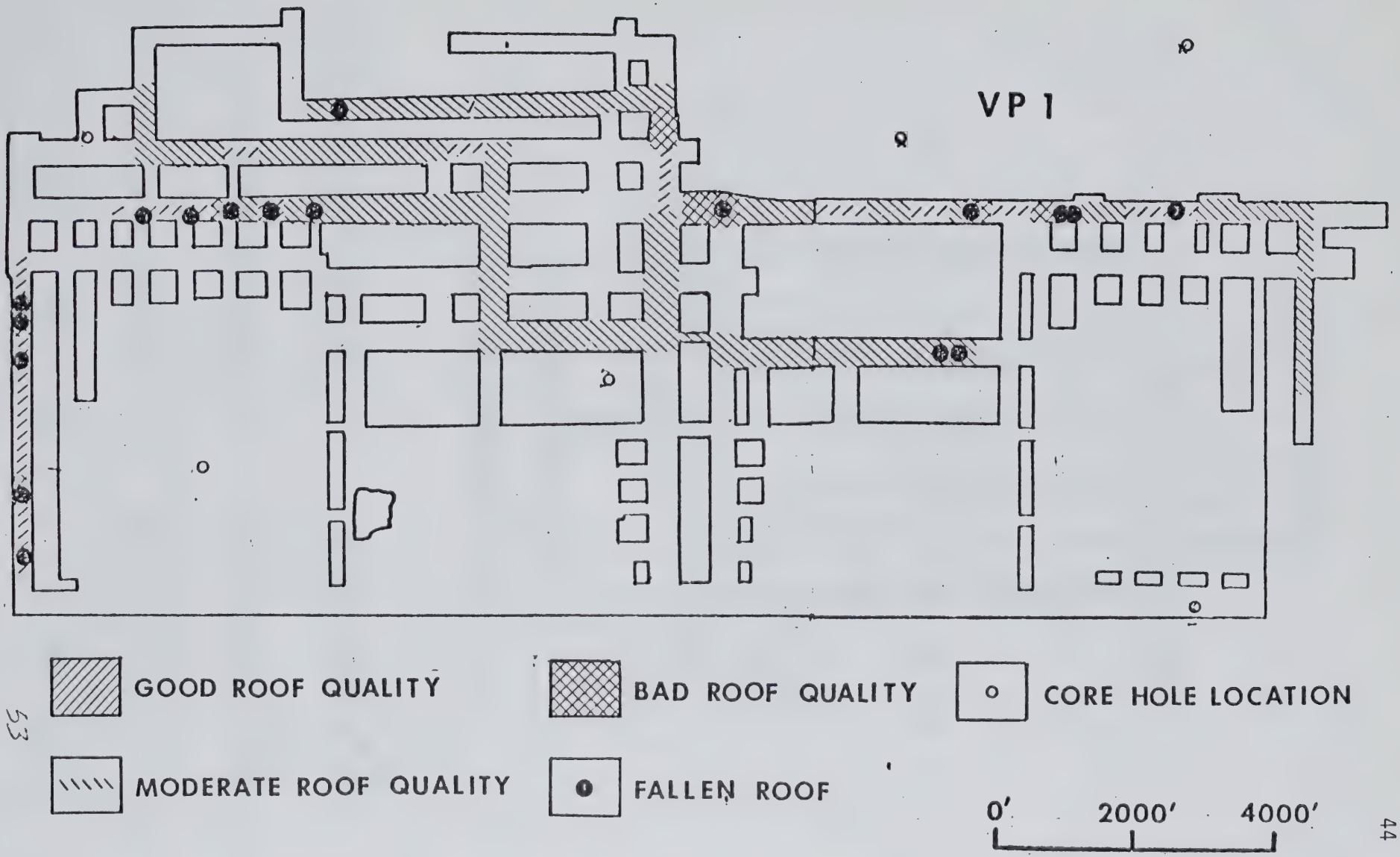


FIGURE 15 ROOF QUALITY IN THE VIRGINIA POCAHONTAS #1 MINE.

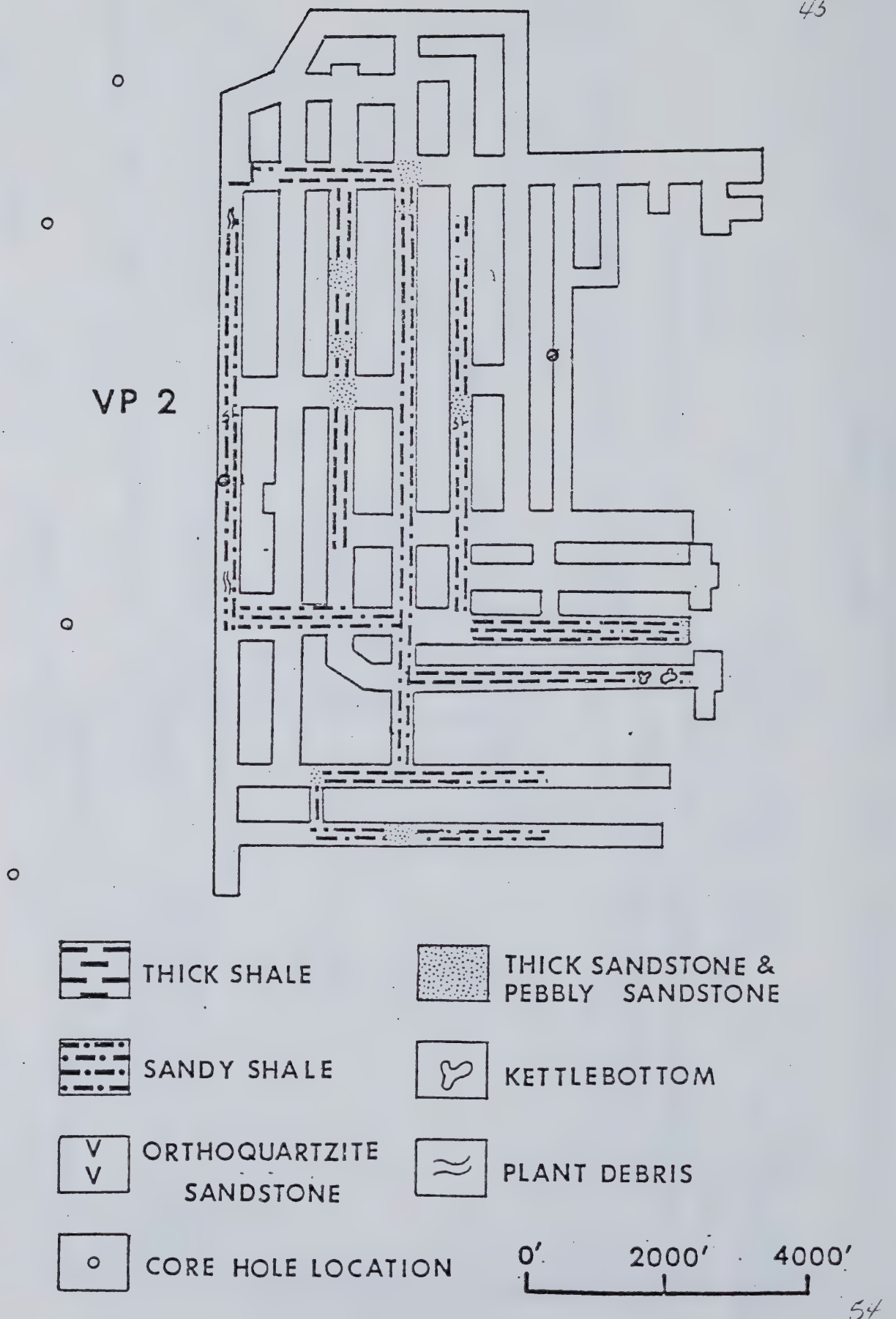


FIGURE 16 ROCK TYPES IN THE VIRGINIA POCAHONTAS # 2 MINE.

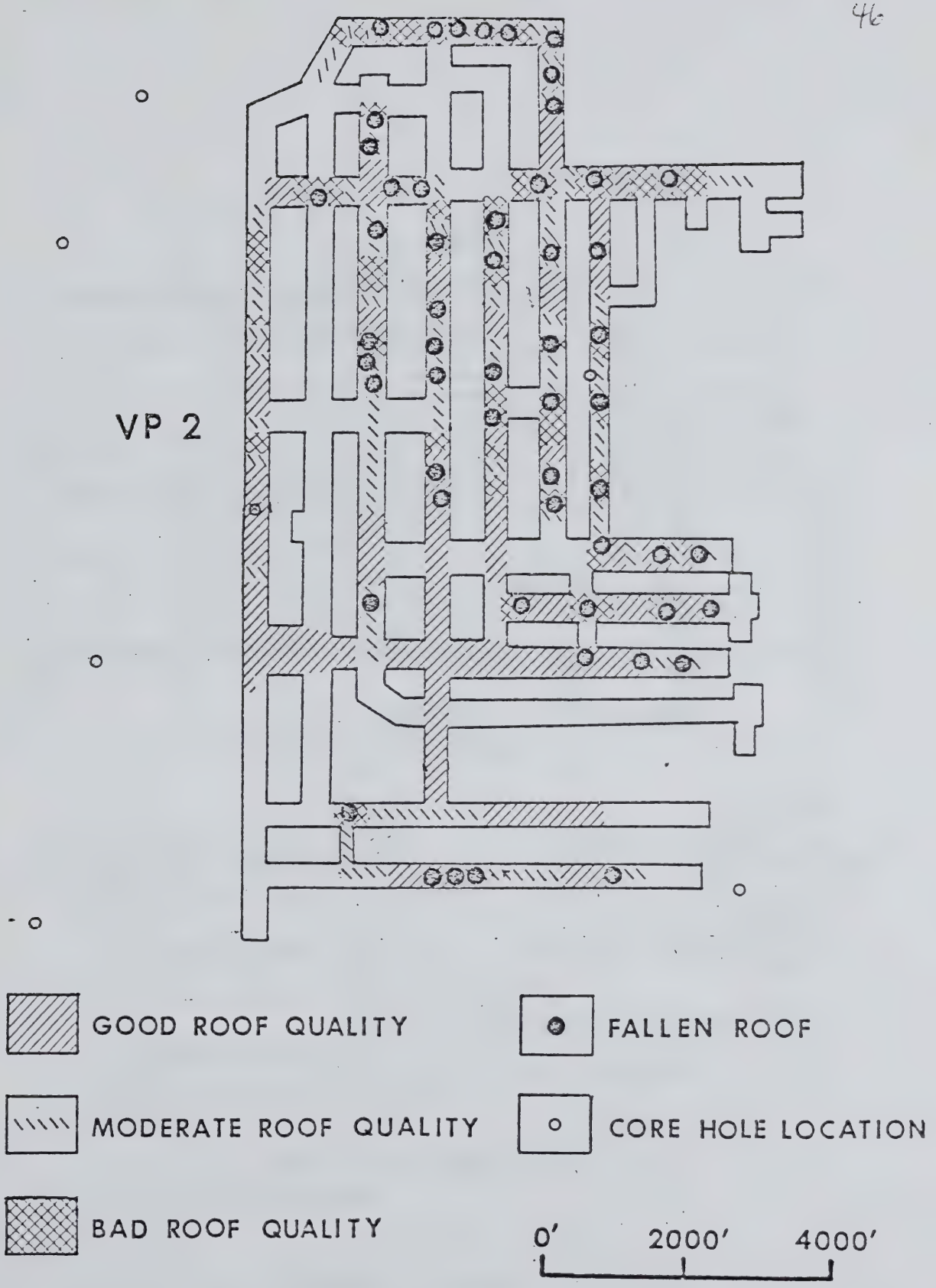


FIGURE 17 ROOF QUALITY IN THE VIRGINIA POCAHONTAS # 2 MINE.

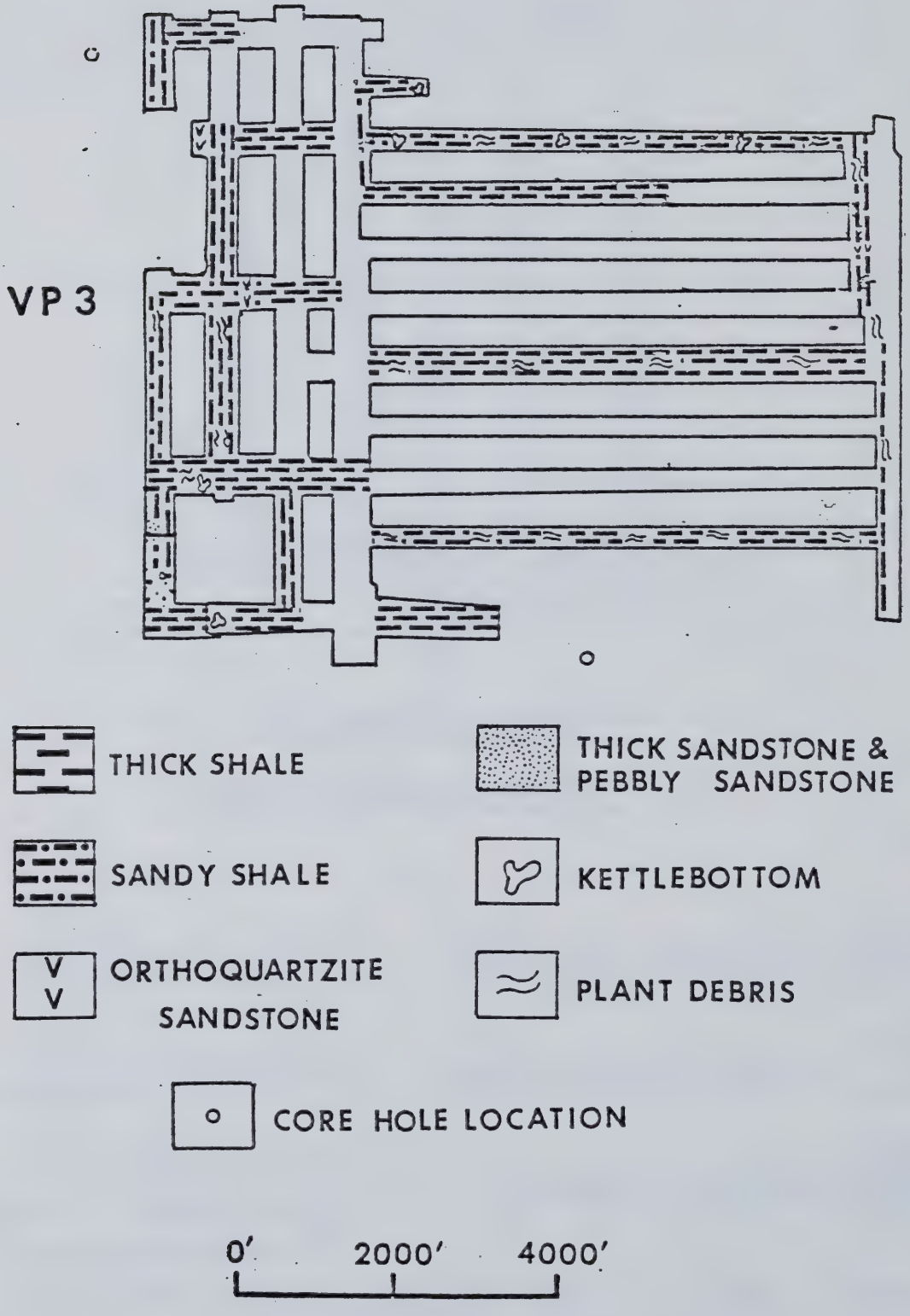


FIGURE 18 ROCK TYPES IN THE VIRGINIA POCAHONTAS # 3 MINE.

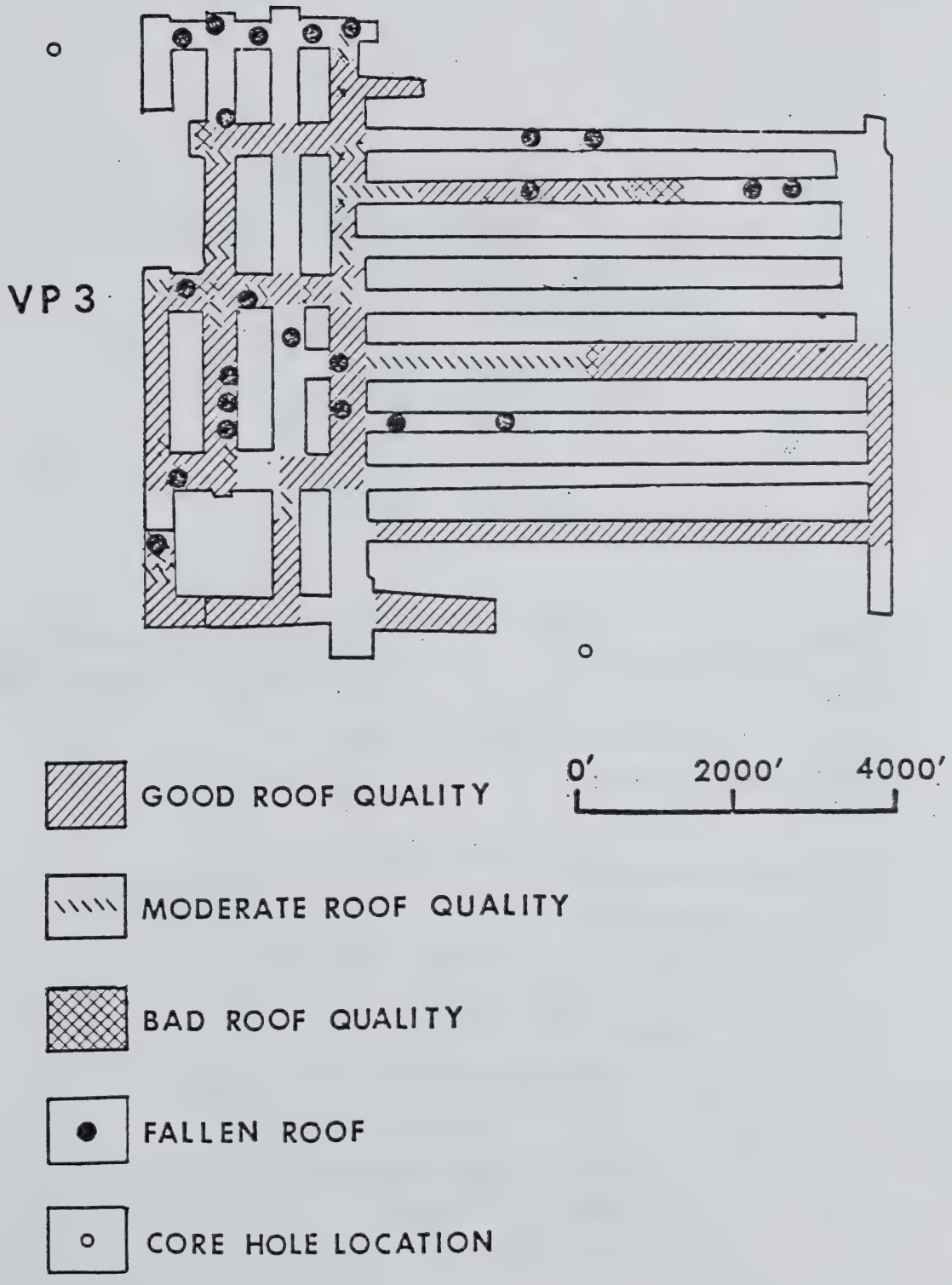


FIGURE 19 ROOF QUALITY IN THE VIRGINIA POCAHONTAS # 3 MINE.

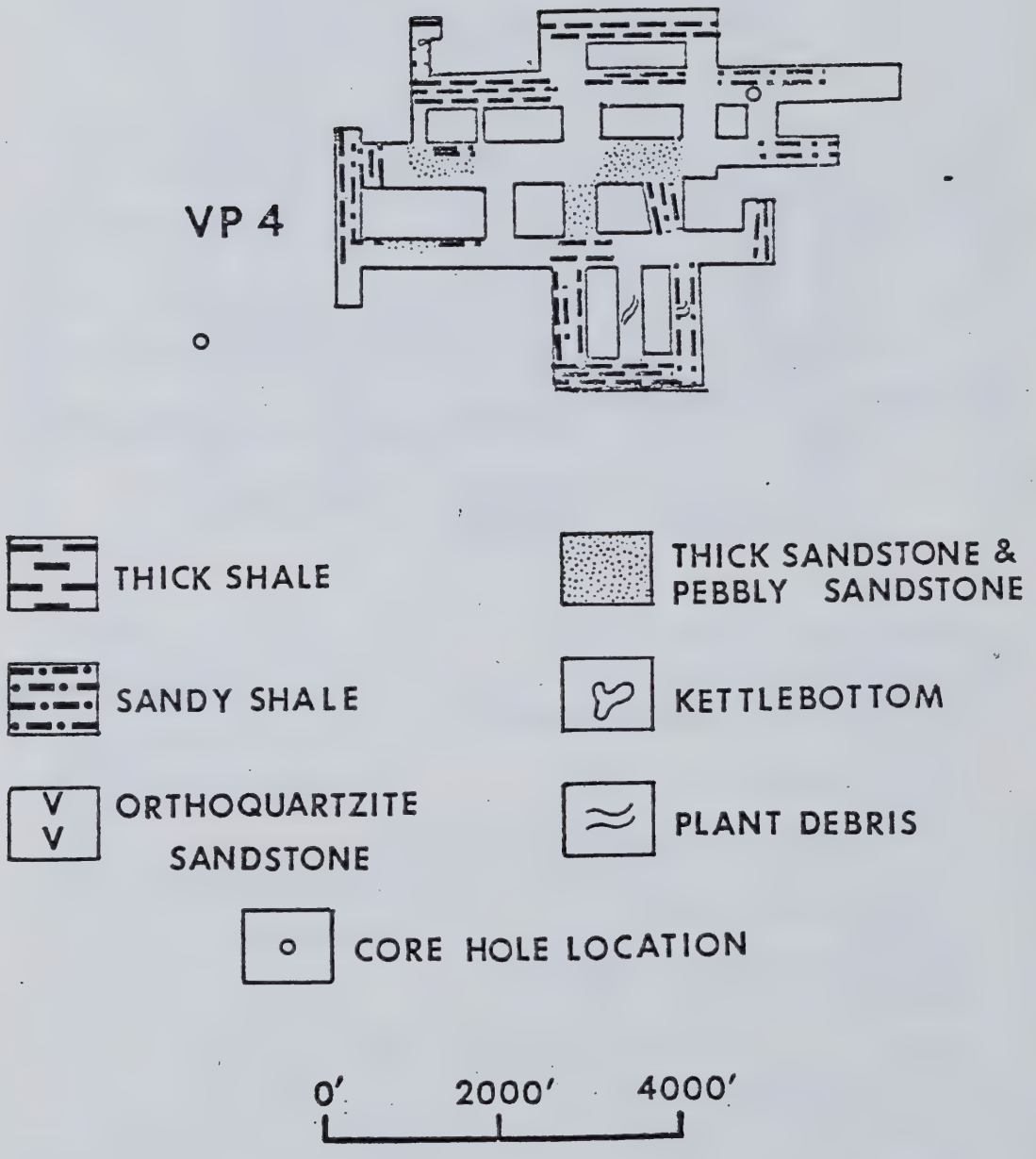
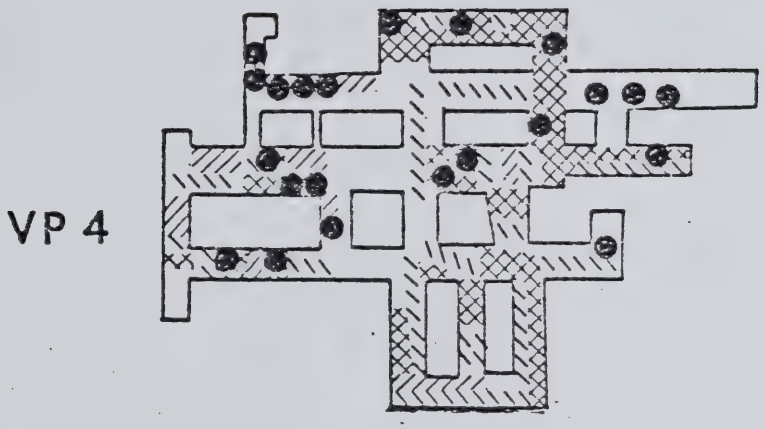


FIGURE 20 ROCK TYPES IN THE VIRGINIA POCAHONTAS # 4 MINE.



GOOD ROOF QUALITY

MODERATE ROOF QUALITY

BAD ROOF QUALITY

FALLEN ROOF

CORE HOLE LOCATION

0′ 2000′ 4000′

FIGURE 21 ROOF QUALITY IN THE VIRGINIA POCAHONTAS # 4 MINE.

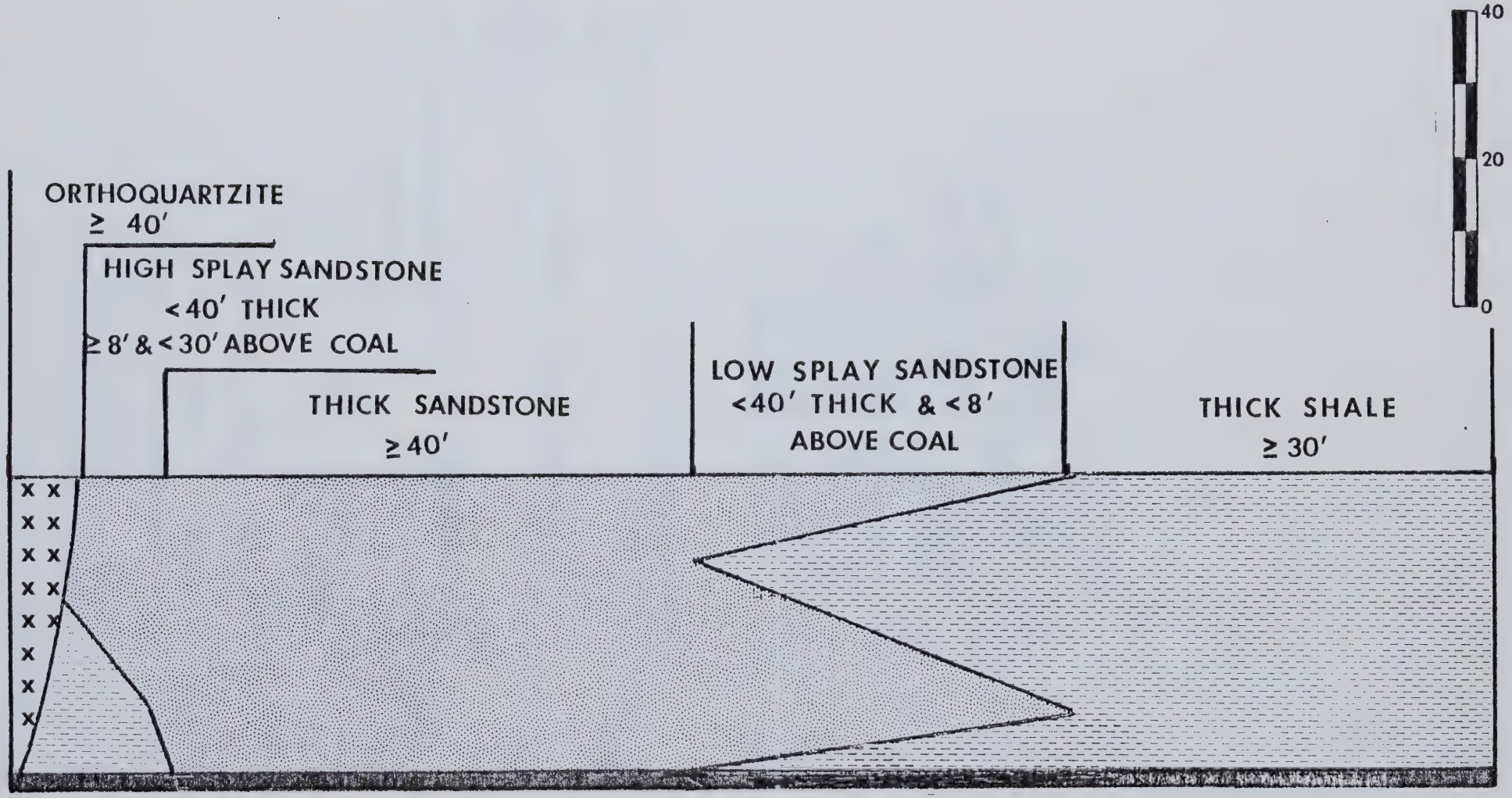


FIGURE 22. A MODEL OF LATERAL RELATIONSHIPS OF THE ROCK TYPES AND SEQUENCES IN THE VIRGINIA POCAHONTAS DIVISION, ISLAND CREEK COAL COMPANY.

specified quality differed between rock types. Such data could prove useful to operating personnel who are experiencing a certain top quality of a specified rock type or rock sequence and want to know over what distance these conditions may be expected to continue. Each step in this analysis should be consistent with the quality and quantity of the data from both a statistical and practical viewpoint.

2.4.1 PROCEDURES

The first step in the analysis was to determine whether rock type or rock sequence was associated with roof quality. Because this data is basically qualitative, some sort of enumeration procedure was considered to be most valid. Moreover, because the sample unit of observation was on the order of 10 to 20 feet, the appropriate sampling interval of this data was set somewhat larger at 25 feet. In an operational sense this consisted of laying a straight edge at the scale of 100 feet = one inch marked in 25 foot intervals on the 100 foot = one inch maps prepared in the field (pg. 7, section 2.3) and reduced on figures 12, 13, 14, 15, 16, 17, 18, 19, 20 and 21 and noting both rock type or rock sequence and roof quality at each 25 foot point along the line. Data from adjacent parallel entries and all data from short cross cuts were omitted because in both cases the information was considered redundant. The starting point for each traverse through continuous entry was a randomly selected one foot point of the first 25 feet from either a rock type, rock sequence, or roof quality boundary. This procedure eliminated possible biases of boundary effects.

A total of 14552 points were collected: with 3750 from Beatrice, 3650 from Virginia Pocahontas #1, 4014 from Virginia Pocahontas #2, 2094 from Virginia Pocahontas #3, and 1044 from Virginia Pocahontas #4. The break down of these points with respect to rock type and roof quality are shown on tables 3, 10, 15, 20, 25 in section 2.4.2.1.

The first set of comparisons of the enumeration data were made from individual mines. These consisted of chi square tests of association between four roof quality categories and the number of rock types that occurred in the mine. These tests were, in turn, broken down into orthogonal sets both from the aspect of roof quality and rock type. Finally, data from all mines were combined into a single chi square table. In all tables a test for significance first established a presence or absence of association and the tables were then examined for cells providing the major contribution or contributions to the total chi square. The latter procedure showed which rock types or rock sequences were strongly associated (positively or negatively) with a given roof quality.

The second step in the analysis was directed toward determining whether lengths of entry with "good" or "bad" top differed among rock types or rock sequences. In this case "good" top consisted of areas previously designated "good" or "moderate" and bad top included those that were designated "bad" or "fallen". The measurements for the analysis were derived by measuring the continuous length of entry of each rock type or rock sequence in the "good" top or "bad" top categories. The analytical procedure was a simple analysis of variance.

2.4.2 RESULTS OF THE ANALYSIS PROGRAM (Barr, Goodnight, Sall, Helwig, 1976)

The primary objective of the statistical analysis was to determine whether there is an association between rock types comprising the roof of the mines and the quality of the roof as observed underground and from core hole data. The classifications and definitions of rock types and rock sequences are given in section 2.3.2.1 and roof quality types are defined in section 2.3.2.2. The second objective was to determine whether the length of good or bad top entries differed among rock types or rock sequences.

2.4.2.1 ASSOCIATION OF ROCK TYPE AND ROOF QUALITY

A chi square analysis was used as a test of association between rock type or rock sequence and roof quality. The first step in this analysis was carrying out association tests in each of the five mines which were the subjects of observation.

Results from Beatrice. The results of the tests on Beatrice are on tables 3, 4, 5, 6, 7, 8, and 9. Table 3 shows the overall association of thick sandstone, low splay, high splay and thick shale (there are no orthoquartzite sandstones in Beatrice) and roof quality is characterized by "good", "moderate", "bad", and "fallen". The chi square of 388.3 is highly significant at the .01 level and an examination of the table show major contributions arising from an excess of moderate or fallen roof quality in thick sandstone, an excess of moderate to bad top in low splays and an excess of good top in thick shale. A deficiency of moderate and bad, thick shale top also makes a major contribution.

The general association for Beatrice is broken down into a series of orthogonal sets on tables 4 through 9 that compare groupings of rock types or rock sequences against roof quality. The results of these tests are as follows:

Table 4 shows an excess of thick shale roof with good top and a deficiency of thick shale roof with moderate to bad top compared to an excess of moderate roof for all other rock types grouped together.

Table 5 shows an excess of high splay moderate roof compared to the other rock types.

Table 6 shows a deficiency of thick sandstone with bad top compared with an excess of low splay with bad top.

Table 7 is unlike the previous four tables, roof qualities are grouped into orthogonal sets and compared to the rock types. Tables 8 and 9 are also arranged in this manner. As one would expect from the previous tables, fallen and bad roof have an excess number of occurrences for low splay and a deficiency of thick shale roof.

Table 8 illustrates the excess of low splay roof with bad top and the lack of thick shale roof with bad top compared to the other roof types.

Table 9 shows an excess of moderate top for thick sandstone and low splay roof. There is a deficiency for moderate top in high splay and thick shale rock types.

Table 3	Good		Moderate		Bad		Fallen		Total
	observed	Chi* square	observed	Chi* square	observed	Chi* square	observed	Chi* square	observed
Thick Sandstone	1150	2.9-	221	90.0+	89	.7-	63	62.0+	1523
Low Splay	718	12.5-	177	26.5+	123	49.0+	14	5.6-	1032
High Splay	132	2.7+	0	16.8-	8	.16-	4	.04+	144
Thick Shale	977	24.4+	40	55.8-	20	33.2-	14	5.9-	1051
Total observed	2977		438		240		95		3750

chi square = 388.3 d.f.=9 significant at .01 level

Table 4	Good		Moderate		Bad		Fallen		Total
	observed	Chi* square	observed	Chi* square	observed	Chi* square	observed	Chi* square	observed
Thick Sandstone, Low Splay and High Splay	2000	9.5-	398	21.7+	220	13.0+	81	2.3+	2699
Thick Shale	977	24.4+	40	55.8-	20	33.2-	14	5.9-	1051
Total observed	2977		438		240		95		3750

chi square =163.8 d.f.=3 significant at .01 level

* + indicates excess frequencies for the observed.
- indicates deficient frequencies for the observed.

Table 5	Good		Moderate		Bad		Fallen		Total
	observed	Chi* square	observed	Chi* square	observed	Chi* square	observed	Chi* square	observed
Thick Sandstone and Low Splay	1868	.3-	398	1.2+	212	.1+	77	.02+	2555
High Splay	132	6.0+	0	21.2-	8	1.2-	4	.02-	144
Total observed	2000		398		220		81		2699

chi square=30 d.f.=3 significant at .01 level

Table 6	Good		Moderate		Bad		Fallen		Total
	observed	Chi* square	observed	Chi* square	observed	Chi* square	observed	Chi* square	observed
Thick Sandstone	1150	1.2+	221	1.1-	89	11.1-	63	6.4+	1523
Low Splay	718	1.8-	177	1.6+	123	16.3+	14	9.4-	1032
Total observed	1868		398		212		77		2555

chi square =48.9 d.f.=3 significant at .01 level

* + indicates excess frequencies for the observed.
- indicates deficient frequencies for the observed.

Table 7	Good and Moderate		Bad and Fallen		Total
	observed	Chi* square	observed	Chi* square	observed
Thick Sandstone	1371	.2-	152	1.8+	1523
Low Splay	895	2.1-	137	21.8+	1032
High Splay	132	.006+	12	.06-	144
Thick Shale	1017	3.7+	34	38.2-	1051
Total observed	3415		335		3750

chi square =67.9 d.f.=3 significant at .01 level

Table 8	Good and Moderate		Bad		Total
	observed	Chi* square	observed	Chi* square	observed
Thick Sandstone	1371	.03+	89	.5-	1460
Low Splay	895	3.3-	123	47.3+	1018
High Splay	132	.01+	8	.2-	140
Thick Shale	1017	2.4+	20	34-	1037
Total observed	3415		240		3655

chi square =87.7 d.f.=3 significant at .01 level

* + indicates excess frequencies for the observed.
- indicates deficient frequencies for the observed.

Table 9	Good		Moderate		Total
	observed	Chi* square	observed	Chi* square	observed
Thick Sandstone	1150	1.7-	221	11.6+	1371
Low Splay	718	5-	177	33.7+	895
High Splay	132	2.5+	0	16.9-	132
Thick Shale	977	9.2+	40	62.7-	1017
Total	2977		438		3415

chi square = 143.3 d.f.= 3 significant at .01 level

* + indicates excess frequencies for the observed.
- indicates deficient frequencies for the observed.

The preceding tests from the Beatrice data indicate a positive association of thick sandstone with moderate and fallen top, a positive association of low splay deposits with moderate or bad top and a positive association of thick shale roof with good top. Negative associations are noted between moderate, bad and fallen top and thick shale and between moderate top and high splay deposits.

Results from Virginia Pocahontas #1. The results of the tests on Virginia Pocahontas #1 are shown on tables 10, 11, 12, 13, and 14. Table 10 contains the overall association of thick sandstone, low splay and thick shale (high splay and orthoquartzite sandstones do not occur in Virginia Pocahontas #1) with "good", "moderate", "bad" and "fallen" quality of top. The total chi square of 154.7 is highly significant at the .01 level. Inspection of the table shows an excess of thick shale with good top compared to a deficiency of thick shale with moderate top. Another contributor is an excess of thick sandstone with moderate top.

The general association for Virginia Pocahontas #1 is broken down into four orthogonal sets on table 11, 12, 13, and 14. The rock types or rock sequences are grouped together in tables 11 and 12 and the roof qualities are grouped on tables 13 and 14. The results of these tests are as follows:

Table 11 indicates an excess of thick shale with good top and a deficiency of thick shale with moderate top compared to the other rock types.
Table 12 shows an excess of moderate thick sandstone roof.
Table 13 is not significant.
Table 14 is not significant.

The tests of the data from Virginia Pocahontas #1 support the previous conclusions in Beatrice. Thick shale is positively associated with good roof and negatively associated with moderate roof. Thick sandstone is positively associated with moderate roof but other associations noted in Beatrice are not present here.

Results from Virginia Pocahontas #2. The test results performed on Virginia Pocahontas #2 are shown on tables 15, 16, 17, 18, and 19. Table 15 shows the overall association of thick sandstone, low splay and thick shale (high splay and orthoquartzite sandstone are absent in this mine) with the roof quality categories "good", "moderate", "bad", and "fallen". The total chi square of 786.8 is highly significant at the .01 level. An examination of the table shows major contributions arising from an excess of good top composed of thick shale, an excess of bad top composed of thick sandstone, a deficiency of bad thick shale top and a deficiency of good top made of thick sandstone. Minor contributions arise from an excess of good top made of low splay deposits and a deficiency of low splay roof with bad top.

The general association for Virginia Pocahontas #2 is broken down into four orthogonal sets, the first two grouping rock types or rock sequences and the second two grouping roof qualities. The results of these tests are as follows:

Table 16 shows an excess number of thick shale roof with good top and a deficiency of thick shale roof with bad top compared to all other rock types.

Table 10	Good		Moderate		Bad		Fallen		Total
	observed	Chi* square	observed	Chi* square	observed	Chi* square	observed	Chi* square	observed
Thick Sandstone	203	12.7-	112	53.4+	22	.04-	12	1.3+	349
Low Splay	1475	2.6-	380	5.7+	142	.26+	65	4.0+	2062
Thick Shale	1046	15.9+	103	48.5-	77	.30-	13	10.0-	1239
Total observed	2724		595		241		90		3650

chi square = 154.7 d.f. = 6 significant at .01 level .

Table 11	Good		Moderate		Bad		Fallen		Total
	observed	Chi* square	observed	Chi* Square	observed	Chi* square	observed	Chi* square	observed
Thick Sandstone and Low Splay	1678	8.2-	492	24.9+	164	.14+	77	5.2+	2411
Thick Shale	1046	15.9+	103	48.5-	77	.30-	13	10.0-	1239
Total observed	2724		595		241		90		3650

chi square = 113.2 d.f. = 3 significant at .01 level

* + indicates excess frequencies for the observed.
- indicates deficient frequencies for the observed.

Table 12	Good		Moderate		Bad		Fallen		Total
	observed	Chi* square	observed	Chi* square	observed	Chi* square	observed	Chi* square	observed
Thick Sandstone	203	6.5-	112	23.4+	22	.1-	12	.07+	349
Low Splay	1475	1.1+	380	3.9-	142	.02+	64	.01-	2062
Total observed	1678		492		164		77		2411

chi square=35.1 d.f.=3 significant at .01 level

Table 13	Good and Moderate		Fallen and Bad		Total
	observed	Chi* square	observed	Chi* square	observed
Thick Sandstone	315	.02-	34	.2+	349
Low Splay	1855	.2-	207	2.1+	2062
Thick Shale	1149	.4+	90	4.4-	1239
Total observed	3319		331		

chi square=7.3 d.f.=3 significant at .10 level

* + indicates excess frequencies for the observed.
- indicates deficient frequencies for the observed.

Table 14	Good and Moderate		Bad		Total
	observed	Chi* square	observed	Chi* square	observed
Thick Sandstone	315	.2+	22	.002-	337
Low Splay	1855	.8+	142	.8-	1997
Thick Shale	1149	1.0+	77	.2-	1226
Total observed	3319		241		3560

chi square=3 d.f.=3 significant at .50 level

* + indicates excess frequencies for the observed.
  - indicates deficient frequencies for the observed.

Table 15	Good		Moderate		Bad		Fallen		Total
	observed	Chi* square	observed	Chi* square	observed	Chi* square	observed	Chi* square	observed
Thick Sandstone	654	133.9-	886	4.7+	769	150.5+	130	13.1+	2439
Low Splay	163	16.0+	111	2.4+	10	39.4-	0	11.0-	284
Thick Shale	869	196.9+	359	13.6-	37	193.6-	26	11.7-	1291
Total observed	1686		1356		816		156		4014

chi square=786.8 d.f.=6 significant at .01 level

Table 16	Good		Moderate		Bad		Fallen		Total
	observed	Chi* square	observed	Chi* square	observed	Chi* square	observed	Chi* square	observed
Thick Sandstone and Low Splay	817	94.3-	997	6.5+	779	91.9+	130	5.5+	2723
Thick Shale	869	197.0+	359	13.6-	37	193.6-	26	11.7-	156
Total observed	1686		1356		816		156		4014

chi square=614.1 d.f.=3 significant at .01 level

* + indicates excess frequencies for the observed.
- indicates deficient frequencies for the observed.

Table 17	Good		Moderate		Bad		Fallen		Total
	observed	Chi* square	observed	Chi* square	observed	Chi* square	observed	Chi* square	observed
Thick Sandstone	654	8.3-	886	.05-	769	7.3+	130	1.6+	2439
Low Splay	163	71.0+	111	.4+	10	62.4-	0	13.5	284
Total observed	817		997		779		130		2723

chi square=164.5 d.f.=3 significant at .01 level

Table 18	Good and Moderate		Bad and Fallen		Total
	observed	Chi* square	observed	Chi* square	observed
Thick Sandstone	1540	51.4-	899	161.0+	2439
Low Splay	274	16.1+	10	50.2-	284
Thick Shale	1228	63.7+	63	199.3-	1291
Total observed	3042		972		4014

chi square=541.7 d.f.=3 significant at .01 level

* + indicates excess frequencies for the observed.
- indicates deficient frequencies for the observed.

Table 19	Good and Moderate		Bad		Total
	observed	Chi* square	observed	Chi* square	observed
Thick Sandstone	1540	43.1-	769	161.2+	2309
Low Splay	274	11.2+	10	41.8-	284
Thick Shale	1228	53.3+	37	198.6-	1265
Total observed	3042		816		3858

chi square=509.2 d.f.=3 significant at .01 level

7.3

* + indicates excess frequencies for the observed.
- indicates deficient frequencies for the observed.

Table 17 shows an excess of low splay deposits with good roof and a deficiency of bad roof compared to the other rock types.

Table 18 shows a deficiency of good or moderate top made of thick sandstone and an excess of bad top made of the same rock type. Thick shales in occurring good or moderate top are in excess and are deficient in bad or fallen top. Low splays are similar to thick shales

Table 19 shows an excess of thick sandstone making up bad top. Low splay has a deficiency of bad top as does thick shale.

As in tests of data from other mines, thick shale roof in Virginia Pocahontas #2 is positively associated with good top and negatively associated with bad top. Unlike Beatrice and Virginia Pocahontas #1, the low splay deposits are positively associated with good to moderate roof and negatively with bad roof. Thick sandstone as in other mines is positively associated with bad roof and negatively with good roof.

Results from Virginia Pocahontas #3. The results of the test of Virginia Pocahontas #3 are shown on tables 20, 21, 22, 23, and 24. Table 20 shows the overall association of thick sandstone, orthoquartzite sandstone, and thick shale (no low splay or high splay units occur) compared to the roof qualities "good", "moderate", "bad", and "fallen". The total chi square of 162.7 is significant at the .01 level with major contributions arising from the excess of thick sandstone roof with bad top.

The general associations for Virginia Pocahontas #3 are broken down into four orthogonal sets on table 21, 22, 23, and 24. The test results are as follows:

Table 21 shows a deficiency of thick shale bad roof as compared to an excess of bad top made of thick sandstone and orthoquartzite sandstone.

Table 22 is significant but shows no major contributions.

Table 23 groups the roof quality and compares them to the individual rock types or rock sequences. There is an excess number of bad or fallen top occurences made of thick sandstone and a deficient number of bad or fallen top occurrences made of orthoquartzite sandstone and thick shale.

Table 24 shows orthoquartzite sandstone and thick sandstone bad roof occurrences to be in excess with a deficiency of thick shale with bad roof.

Unlike the previous mines, the tests from Virginia Pocahontas #3 show that thick shale is not positively associated with good roof but it is negatively associated with bad roof. Similarly thick sandstone, is not negatively associated with good roof but is positively associated with bad roof. Virginia Pocahontas #3 is the only mine having orthoquartzite sandstone and it is associated with bad roof.

Results from Virginia Pocahontas #4. The test results for Virginia Pocahontas #4 are found in tables 25 and 26. Table 25 indicates overall associations between thick sandstone and low splay (high splay, thick shale and orthoquartzite sandstones do not occur in this mine) as compared

Table 20	Good		Moderate		Bad		Fallen		Total
	observed	Chi* square	observed	Chi* square	observed	Chi* square	observed	Chi* square	observed
Thick Sandstone	29	.7-	0	4.9-	8	18.0+	5	13.8+	42
Orthoquartzite Sandstone	324	11.7-	83	11.8+	62	67.4+	14	.06+	483
Thick Shale	1338	3.97+	164	2.4-	29	27.5-	39	.5-	1569
Total observed	1691		247		99		57		2094

chi square=162.7 d.f.=6 significant at .01 level

Table 21	Good		Moderate		Bad		Fallen		Total
	observed	Chi* square	observed	Chi* square	observed	Chi* square	observed	Chi* square	observed
Thick Sandstone and Orthoquartzite Sandstone	353	11.9-	83	7.2+	70	82.4+	19	1.5+	525
Thick Shale	1338	3.9+	164	2.4-	29	27.5-	38	.5-	1569
Total observed	1691		247		99		57		2094

chi square=137.3 d.f.=3 significant at .01 level

* + indicates excess frequencies for the observed.
- indicates deficient frequencies for the observed.

Table 22	Good		Moderate		Bad		Fallen		Total
	observed	Chi* square	observed	Chi* square	observed	Chi* square	observed	Chi* square	observed
Thick Sandstone	29	.02+	0	6.6-	8	1.0+	5	8.2+	42
Orthoquartzite Sandstone	324	.002-	83	.57+	62	.09-	14	.7-	483
Total observed	353		83		70		19		525

chi square = 17.2 d.f. = 3 significant at .01 level

Table 23	Good and Moderate		Fallen and Bad		Total
	observed	Chi* square	observed	Chi* square	observed
Thick Sandstone	29	2.5-	13	31.6+	42
Orthoquartzite Sandstone	407	3.6+	76	44.4-	483
Thick Shale	1502	1.7+	67	21.3-	1569
Total observed	1938		156		2094

chi square = 105.1 d.f. = 3 significant at .01 level

* + indicates excess frequencies for the observed.
  - indicates deficient frequencies for the observed.

Table 24.	Good and Moderate		Bad		Total
	observed	Chi* square	observed	Chi* square	observed
Thick Sandstone	29	1.1-	8	21.3+	37
Orthoquartzite Sandstone	407	3.4-	62	67.4+	469
Thick Shale	1502	1.4+	29	27.7-	1531
Total observed	1938		99		2037

chi square=122.3 d.f.=3 significant at .01 level

* + indicates excess frequencies for the observed.
  - indicates deficient frequencies for the observed.

Table 25	Good		Moderate		Bad		Fallen		Total
	observed	Chi* square	observed	Chi* square	observed	Chi* square	observed	Chi* square	observed
Thick Sandstone	154	2.0+	238	5.1+	225	.2-	50	.6-	665
Low Splay	117	3.5-	85	8.7-	139	.37+	38	1.2	379
Total observed	271		323		364		88		1044

chi square-21.6 d.f.=3 significant at .01 level

Table 26	Good and Moderate		Fallen and Bad		Total
	observed	Chi* square	observed	Chi* square	observed
Thick Sandstone	392	.5+	275	.6-	665
Low Splay	202	.86-	177	1.0+	379
Total observed	594		452		1044

chi square=2.76 d.f.=3 significant at .50 level

* + indicates excess frequencies for the observed.
- indicates deficient frequencies for the observed.

to the roof categories of "good", "moderate", "bad", and "fallen". The total chi square of 21.6 is significant at the .01 level. The major contribution appears to arise from the low splay rock sequence but its association with a particular roof quality is not clear.

The general association for Virginia Pocahontas #4 is broken into one orthogonal set grouping roof quality and comparing it to the two rock types. These results, found in table 26, are not significant.

Results from all Mines. A final test was conducted grouping all rock types or rock sequences and roof quality data from all mines. The results are found in table 27. The total chi square of 1824.8 is highly significant at the .01 level, with thick sandstone and thick shale being major contributors. As in the tests for previous mines, thick sandstone is negatively associated with good top and positively associated with moderate, bad and fallen top. Likewise thick shale is positively associated with good top and negatively associated with other top qualities.

2.4.2.2 ANALYSIS OF ENTRY LENGTH OF GOOD AND BAD TOP RELATIVE TO ROCK TYPE

The second step in the analysis was conducted to answer the question whether the length of good and bad top entry differed with respect to rock type. Such information should be relevant to operators who, having encountered a particular rock type roof and who are experiencing certain roof quality, want to know how long this particular set of conditions can be expected to prevail. The simplest set of comparisons are the means (averages) of each rock type in conditions of good-moderate or bad-fallen roof. These data, shown on table 28 indicated that the linear distance of good to moderate top is greatest for shale ($\bar{x}$ = 1005.1') and the least for sandstone ($\bar{x}$ = 372.7') with ortho-quartzite, high splay and low splay having intermediate values. In areas of bad top, the differences are not as great as for good top with the greatest being sandstone ($\bar{x}$ = 168.4) and the least high splay ($\bar{x}$ = 68.7).

Although there are apparent differences between means for length of entry having different rock types in the roof, it is necessary to verify these data through an analysis of variance procedure. Two separate analyses have been made for good and bad top repsectively and the results are shown on tables 29 and 30. In examining these tables it should be noted that possible effects of the direction of entry are taken into consideration. There was no indication during the measurement program that the bearing of the entry (east-west vs. north-south) was in any way related to roof quality but this factor was included in the analysis simply to confirm a field observation.

Before the analysis could be made, the values were transformed to $\log_{10}$ in order to normalize the distributions. High splay values were omitted from both analyses because the very small number of observations in this rock type tend to invalidate the analysis.

Table 27	Good		Moderate		Bad		Fallen		Total
	observed	Chi* square	observed	Chi* square	observed	Chi* square	observed	Chi* square	observed
Sandstone	2190	332.0-	1455	186.6+	1113	421.6+	260	50.9+	5018
Orthoquartzite Sandstone	324	.60+	83	2.3-	62	.22+	14	.27-	483
Low Splay	2473	1.47+	753	.15-	414	3.6-	117	.58-	3757
High Splay	132	16.9+	0	29.3-	8	5.1-	4	.13-	144
Thick Shale	4230	256.8+	666	138.7-	163	339.5-	91	38.1-	5150
Total observed	9349		2957		1760		486		14,552

chi square = 1824.8 d.f. = 12 significant at .01 level

* + indicates excess frequencies for the observed.
  - indicates deficient frequencies for the observed.

Table 28 Means for linear entry distances of good-moderate and bad-fallen top composed of thick sandstone, low splay and high splay deposits, orthoquartzite sandstone and thick shale.

Areas of Good and Moderate Top		
Rock Type	Mean	Number of Observations
Thick sandstone	372.7'	378
Low splay	598.3'	248
High splay	546.7'	6
Orthoquartzite Sandstone	761.4'	14
Thick shale	1005.1'	138

Areas of Bad and Fallen Top		
Rock Type	Mean	Number of Observations
Thick Sandstone	168.4'	333
Low splay	125.0'	171
High splay	68.7'	4
Orthoquartzite Sandstone	131.8'	11
Thick shale	88.8'	81

Table 29 Analysis of variance of rock types in linear distances of entry with good and or moderate top. Data transformed to $\log_{10}$ and high splay areas omitted.

Sources	Sum of Squares	Degrees of Freedom	F	Significant at:
Direction	0.256	1	1.17	.280
Rock type	17.057	3	25.97	.001**
Direction x Rock Type	1.501	3	2.29	.076*
Error	168.584	770		

**highly significant *moderately significant

Table 30 Analysis of variance of rock types in linear distances of entry with bad and fallen top. Data transformed to $\log_{10}$ and high splay areas omitted.

Sources	Sum of Squares	Degrees of Freedom	F	Significant at:
Direction	0.101	1	.46	.496
Rock Type	2.969	3	4.57	.004*
Direction x Rock Type	1.549	3	2.38	.067*
Error	127.408	588		

**highly significant *moderately significant

As the results on tables 29 and 30 show, the direction of entry has no effect, with either "good" (good and moderate) or "bad" (bad and fallen) top entries having about equal length in either east-west or north-south direction. In the case of rock type, however, the results are highly significant in both "good" and "bad" top tests. It should be emphasized, however, that in the case of bad or fallen top that the greatest differences are only about 100 feet which is of little practical importance. On the other hand, in areas of "good" top, linear distances for shale are considerably greater than for sandstone and probably somewhat greater than for areas of low and high splay.

2.4.3 SUMMARY OF RESULTS OF ANALYSES

The chi square tests of association of roof rock type or rock sequence and roof quality is not entirely consistent but the results are relatively clear for two rock types - thick shale and thick sandstone. Thick shale clearly emerges as producing the best quality roof in the Virginia Pocahontas mines being, in most cases, positively associated with good roof quality and negatively associated with moderate, bad or fallen top. It is also reasonably clear that, among the commonly occurring rock types or sequences, thick sandstone is the poorest quality being positively associated with moderate bad and fallen top in almost every case and negatively associated with good top in some mines.

The results of the analysis for the average lengths of entry of "good" and "bad" top show similar results for thick shale and thick sandstone. The average length of thick shale entry of good or moderate quality is about 1000 feet whereas for thick sandstone top of the same quality the average length is only about 375 feet. In contrast sandstone entries of bad or fallen quality average about 170 feet whereas thick shale topped entries of the same quality average about 90 feet.

The results of the association tests for low splay deposits are ambiguous: in some cases these rocks are positively associated with moderate to good quality and, in other cases, bad quality. A comparison of the length of good and bad top entry for low splay deposits verses other rock types yield similar results. In entries of good or moderate quality, the average for low splay deposits is about 600 feet, neither as great as thick shale nor as small as thick sandstone. Likewise in low splay entries of bad or fallen top the average length is neither as small as thick shale nor as large as thick sandstone. These results may arise from the definition of this rock type (see section 2.3.2.1 and figure 23) in which some splay deposits approach the character of thick sandstone and others, thick shale.

High splay deposits and orthoquartzite sandstones probably occur too infrequently relative to other roof rock types to obtain unequivocal results. Where they do occur, however, high splays are not clearly associated with extremely good or bad quality and the mean length of good or moderate top entry is very similar to low splay deposits. The average length of entry with bad or fallen top, however, is only about 70 feet, which is lower than thick shale. Orthoquartzite sandstones

appear to be associated with bad roof quality and the mean length of entry with bad or fallen top approach that of thick sandstone. Where this rock type is found in the good and moderate roof quality, however, the mean entry length approaches that of thick shale.

3.0 SUMMARY OF RESULTS FROM PAHSE II AND III

The objective of this summary is to compare the results of the Phase III study of the Virginia Pocahontas mines with those obtained from the Phase II study of West Virginia mines with the view of determining which rock type, types or sequences provide roof of the best quality and which ones the poorest. In design of the Phase III experiments, specific criteria were established for good, moderate, bad and fallen top and all five Virginia Pocahontas mines were compared on this basis. In contrast, the five mines studied in Phase II were selected to show the greatest spectrum of variation in mining, geologic and roof conditions and, within each mine, judgements of "good" and "bad" top quality were based on the experience in that particular mine. As a consequence, some of the "bad" top observed in Phase II was much worse than anything encountered in Phase III and, within an individual mine in Phase II, the "good" top is only "good" by comparison within that mine and, in some cases, would be judged no better than "moderate in mines studied in Phase III.

Despite these difficulties one major conclusion emerges -- namely that coarsening upward shale-sandy shale-sandstone sequences on the order of 30 feet thick provide top of the best quality. This emerged clearly from the analysis of the Virginia Pocahontas data and is in agreement with the study of the Shannon Branch mine where the same type of sequence was found in the good top area during Phase II. In the latter case, however, the coarsening upward shale sequence in a "good" top area was compared to a "bad" top area which had the worst top seen anywhere during the entire investigation.

Ambiguous results are obtained when the roof quality of thick sandstone is compared in Phase II and III. In the Virginia Pocahontas mines, thick sandstone is associated with fallen, bad or moderate quality and was considered the poorest top material. In contrast, thick sandstone top in Keystone II, Bishop and Macalpin-East Gulf was judged "good". There are several possible reasons for this. The primary reason probably lies in the presence of shale and ironstone pebbles and coaly strips which are abundant in the lower three or four feet of the thick sandstones in the Virginia Pocahontas mines. In these mines, such material is closely associated with strong cross bedding and is the site of numerous falls. In contrast, cross bedded gravelly zones make up only a small proportion of the thick sandstones in the good top areas of Macalpin-East Gulf, Keystone II and Bishop, but, where they do occur elsewhere in the mines, they are associated with bad or fallen top.

A second reason for the ambiguous results for thick sandstone in Phase II and Phase III may lie in the rock types other than thick sandstone found in the West Virginia mines studied in Phase II compared to the Virginia Pocahontas mines studied in Phase III. In the West Virginia Phase II mines, the sandstone roof area is judged "good" compared to "bad" top areas composed of underclay or seat earth, a very unstable top material. Such material does not occur in the Virginia Pocahontas mines and thick sandstones there are compared to "coarsening" upward thick shale units, which are the best top materials encountered during the study. Hence, the judgement of "good"

top in Keystone II, Bishop, and Macalpin-East Gulf is based on a comparison with very unstable top material and, were thick shales present in these mines, the judgement of the quality of the thick sandstone may have been somewhat different.

The results of the study of low splay deposits seem to be reasonably consistent both in Phases II and III. In the Virginia Pocahontas Phase III data, low splays yielded highly varying quality top but, overall, are neither as good as thick shale nor as poor as thick sandstone. This variation was believed to result from the thickness of the sandstone unit making up these deposits. In Keystone II, Macalpin-East Gulf and Bishop, studied in Phase II, low splay deposits with thin sandstones (less than 10 feet thick) were found in bad top areas. In the latter cases, however, these sandstones were accompanied by fire clay which probably contributed to their low quality.

Fire clays or sandy fire clays - collectively termed seat rock or "clod" rock - do not occur in any significant quantity in the Phase III Virginia Pocahontas mines and hence there is no direct way to compare results. It is evident, however, that the quality of the roof composed of such rocks would rank well below any of the rock types or sequences observed in the Virginia Pocahontas mines and are among the poorest quality roof materials in the area. In Keystone II and Bishop such rocks either form the immediate roof and are overlain by a rider coal or are found overlying or interbedded with a thin (0 to 10 feet) splay sandstone. Where the sandstone attains a thickness in excess of 10 feet, a bridging effect takes place and the roof is relatively stable. Where the sandstone is thin, however, and bolts anchor into the seat earth, the results are not much better than uniform seat earth sequences. Very clayey seat earths are even less stable and are particularly dangerous when wetted, falling as a slippery, crumbly mass.

The remaining two rock types observed in the Virginia Pocahontas Phase III study - high splay deposits and orthoquartzite sandstone - were not found in the Phase II West Virginia mines and hence a direct comparison cannot be made. Their minor occurrence even in the Phase III data made specific designation with respect to roof quality even more difficult. It would appear that high splays provide a somewhat better top than orthoquartzite sandstone and neither provide top as satisfactory as coarsening upward shale sequences.

One of the greatest lithologic contributors to roof falls in the Pocahontas #3 area are slickensides. In addition to their occurrence in seat earths or fire clays they are also found at the contact between channel scour sandstones and finer grained rocks and associated with ancient slump deposits. Slickensides along channel scours were observed both in the Phase II and Phase III studies and in all cases, the finer grained rocks fall away from the slicked contact with the sandstone. In some cases this effect is relatively local but in others, such as Keystone II, the finer-grained rock includes seat earth and a rider coal and there is a greater tendency for larger and more severe falls.

Without question, the worst top in the study was associated with slickensides due to penecontemporaneous slumping in the Shannon Branch mine observed in the Phase II study. No such occurrences were observed

in Phase III. In the slumped areas, large closely spaced slickenside planes extend upward for at least 30 feet into the roof and separate inclined blocks of shale, sandy shale, sandstone, seat earth and rider coal. No conventional support technique is effective and there is some question whether steel trusses now in use will ultimately be able to provide support.

4.0 A SUMMARY FOR OPERATING PERSONNEL

The preceding portions of this report document in detail some of the geologic characteristics or conditions that have been found to be associated with roof falls in underground mines on the Pocahontas #3 coal seam in southern West Virginia and southwestern Virginia. The method of presentation of these results, however, is of such length and complexity that operating personnel, whose time is limited by day to day mining problems, do not have ample time to study the entire report. Hence the following summary is presented to emphasize the primary results that should be helpful to operating people in planning new mines, extending existing mines or in day to day operations.

The primary result of this study is that slickensided rock produces the worst roof problems in Pocahontas #3 mines. These slick, shiny polished surfaces are found in a number of different rock types and geologic settings but in almost every case are associated with roof problems of varying degrees of severity. Below are listed the primary geologic conditions in which slickensides have been found in fallen roof rocks and suggested ways of determining their location in advance of mining.

Slickensided Rocks	Methods of Location
Slumped deposits composed of sandstone, shale and other rock types.	Slump deposits can easily be detected in rock core by the presence of strongly inclined (up to 90°) stratification planes and by slickenside surfaces in the core. The presence of fairly large areas such deposits could be detected on a 1500 to 2000 foot drill spacing but closer spacing is required to accurately define the areas in which they occur.
Fire clay and, to a lesser extent, sandy fire clay.	This material can be readily identified in rock core and, in many cases, its location can be mapped from drill hole spacing on the order of 1500 to 2000 feet. In older drillers records, their presence is not often directly recorded but can be inferred beneath thin rider coals.
Sharp lateral contact of sandstone and fine grained rock (shale or fire clay)	These contacts are rarely observed directly in rock core but their general location can be inferred by mapping roof rock from core hole data. When they are encountered in the course of mining, underground personnel should be alerted to them as potential hazard zones.

Sides of some kettle bottoms.	These can be detected only in the course of mining but roof bolters should be alerted to circular coaly strip surrounding them and one or more bolts should be placed diagonally through them.

A rock type which is a secondary cause of roof problems are gray, strongly cross bedded sandstones with abundant shale and ironstone pebbles and coaly strips. Cross bedded gray sandstones with shale, coal and ironstone pebbles occur in limited areas in the basal three or four feet of most thick gray sandstones and their areal distribution can not be readily mapped with core holes spaced at 1500 to 2000 feet. The presence of this material in a large proportion of core holes in any one area, however, may indicate a potentially serious problem. Thick bodies (30 feet thick) of gray sandstone without pebbles and coal strips in the lower part often provide excellent top.

Orthoquartzite sandstones also may be expected to produce roof problems but they are a relatively rare roof rock type and will be found only near the western and northwestern limits of the minable Pocahontas #3 seam in Virginia and adjoining portions of West Virginia.

The best roof material overlying the Pocahontas #3 seam is a shale which grades upward into sandy shale and shaley sandstones within twenty to thirty feet of the top of the seam. This roof rock type can be detected by cores of roof rock spaced at intervals of 1500 to 2000 feet and, where found, its areal distribution should be relatively regular.

REFERENCES CITED

Barr, A. J., Goodnight, J. H., 1972, A User's Guide to the Statistical Analysis System: North Carolina State University, 260 p.

Barr, A. J., Goodnight, J. H., Sall, J. P., Helwig, J. T., 1976, A User's Guide to the Statistical Analysis System 76: SAS Institute, Inc., 329 p.

Bolstad, D. D., Allredte, J. R., Mahtab, M. A., 1973, Procedures Used for Sampling Fracture Orientations in an Underground Coal Mine: Bureau of Mines Report 7763 Investigations., 7 p.

Ferm, J. C., Melton, R. A., 1975, Roof Fall Study Pocahontas #3 Seam, Interim Report, Open file report, U.S. Bureau of Mines, 73 p.

Hinds, H.,1918, The Geology and Coal Resources of Buchanan County, Virginia: Virginia Geol. Survey Bulletin XVIII, Charlottsville, Virginia, 278 p.

Melton, R.A., Ott, D. L., 1977, Coal Exploration and mine planning: Application of computer methods in the mineral industry: AIME, 343-357 p.

Nie, N., Bent, D. H., Hadlaihull, C., 1970, Statistical Package for the Social Science: McGraw-Hill Book Co., 343 p.

Nunnally, J.C., 1967, Psychometric Theory, New York, McGraw Hill.

Shanley, R. J., Mahtab, M. A., 1974, A Computer Program for Clustering Data Points on a Sphere: Bureau of Mines Information Circular 8624, 58 p.

UNIVERSITY OF ILLINOIS-URBANA
3 0112 103719123

SHIPPED FROM NTIS
JAN 26 1981